AN ANALYSIS AND EVALUATION OF CURRENT EFFORTS TO IMPROVE THE CURRICULUM BY EMPHASIS ON DISCIPLINARY STRUCTURE AND LEARNING BY DISCOVERY

By

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CHAPTER I

FORMULATION AND DEFINITION OF THE PROBLEM

Introduction

Recently many proposals for the improvement of the curriculum have attracted the attention of both the public and professional educators. Perhaps the most prominent of these proposals is the one which emphasizes the importance of disciplinary structure and learning by discovery. This proposal is presented in The Process of Education,[1] the report of the Woods Hole Conference held in September, 1959. Thirty-four scientists, educators, and scholars met to discuss ways of improving science education in the public school. However, it was soon decided that the conference should not limit itself to science but should undertake to discuss other areas of the curriculum. From this conference came the impetus behind the efforts to improve the curriculum by emphasis on disciplinary structure and learning by discovery.

The impact of this proposal on school curriculum has been tremendous. Due largely to financial aid from the federal government and private foundations, which have already provided millions of dollars and will undoubtedly provide millions more, thousands of teachers and students have and are utilizing the materials and following the procedures entailed in mastery of disciplinary structure and learning by discovery.

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[1] Jerome S. Bruner, The Process of Education. Cambridge, Mass.: Harvard University Press, 1960.

This proposal has elicited much discussion and reactions to it have varied widely. In light of the attention that has been given to the proposal it is somewhat surprising that a review of the professional literature in education reveals that no comprehensive study has been undertaken to analyze and evaluate the proposal. There have, of course, been numerous studies of the proposal concerned with the analysis, description, and evaluation of one or two aspects or phases of the proposal. But these studies have never been synthesized to develop a broader basis for analysis and evaluation. Also, for the most part, these studies were made to determine the relative effectiveness of a specific subject taught by emphasizing its structure or to compare certain methods of teaching for discovery. There is, then, a need for a study to analyze and evaluate this proposal in terms of its influence in improving the curriculum.

Purpose of the Study

The purpose of this study is to analyze and evaluate the curriculum proposal outlined at the Woods Hole Conference. Specifically this study (1) analyzes and describes the rationale of disciplinary structure and learning by discovery, (2) analyzes and describes three curriculum projects based upon the proposal of the Woods Hole Conference, (3) reviews the evidence used to evaluate the efforts to improve the curriculum by emphasizing disciplinary structure and learning by discovery, (4) presents a critical summary of the analysis and evaluation.

In order to provide additional focus for this study a series of questions to be answered were formulated. These questions are listed below:

1. What is disciplinary structure?

2. How is disciplinary structure identified?

3. What is the rationale of teaching disciplinary structure?

4. What are the advantages of teaching disciplinary structure?

5. What basic assumptions underlie the concept of disciplinary structure?

6. What is learning by discovery?

7. What is the rationale of learning by discovery?

8. What are the advantages of learning by discovery?

9. For what purposes may learning by discovery be utilized?

10. What are the various instruction methods for teaching by discovery?

11. What are the implications of basing curriculum design upon the proposal of the Woods Hole Conference?

12. What are the conclusions that may be based on the evidence used to evaluate the proposal of the Woods Hole Conference?

13. What do the analysis and evaluation of the proposal indicate about its influence on curriculum improvement?

Design of the Study

Basically the study consists of three parts. The first part consists of a survey and analysis of the literature relevant to the proposal of the Woods Hole Conference. This first part actually comprises Chapters II, III, and V. Chapter II presents an analysis of the rationale of disciplinary structure. This analysis focuses on the meaning, description, presentation of examples, identification, advantages, and assumptions of disciplinary structure.

Chapter III analyzes three curriculum projects that emphasize disciplinary structure: the Physical Science Study Committee, the School Mathematics Study Group, and the Biological Sciences Curriculum Study. Each of these three projects is cited by the Woods Hole Conference as exemplars of curriculum based on disciplinary structure. The analysis focuses on four aspects of curriculum design: (1) organization and structure, (2) content selection, (3) sequence, and (4) scope. Material for the analysis was derived from two sources: (1) the texts, teacher's guides, and other materials used in teaching the projects, and (2) a review of the relevant professional literature in education.

Chapter V analyzes learning by discovery. The analysis is divided into five sections. The first section describes the essential characteristics of learning by discovery. The second section reviews the rationale of discovery learning. The third section identifies the advantages claimed for learning by discovery. The fourth section identifies some of the new curriculum proposals which utilize discovery. The final section identifies and describes the various methods of teaching for discovery.

The second part of the study consists of a review of the evidence available to evaluate the proposal of the Woods Hole Conference. This part is comprised of Chapters IV and VI.

Chapter IV reviews the evidence used to evaluate the various curriculum projects emphasizing disciplinary structure. The evidence is organized into the following five topics:

1. Student achievement
2. Reactions of students
3. Reactions of teachers
4. Reactions of parents
5. Reactions of subject-matter specialists.

The evidence was located by a review of the professional literature in education. The chapter concludes with a summary of the evidence.

Chapter VI evaluates the methods of teaching for discovery. The six advantages claimed for discovery learning are used as evaluative criteria. These six criteria are as follows:

1. Discovery learning promotes meaningful learning.
2. It strengthens and extends intellectual potency and cognitive skills.
3. It is intrinsically motivating.
4. It aids transfer of learning.
5. It teaches the heuristics of discovery.
6. It aids memory processes.

The same six criteria plus a seventh criterion, the length of time and number of steps required for discovery, are used to evaluate the relative effectiveness of three methods of teaching for discovery.

The third part of the study consists of a critical summary of the first two parts. The critique is made in terms of (1) the implications of the proposal of the Woods Hole Conference for curriculum design, and (2) the reactions of curriculum experts to the proposal. In addition the writer offers a brief critique of the proposal based upon several observations he has made about the proposal.

Procedure

The point of departure for the analysis was The Process of Education.[1] After this source was fully utilized the available materials of the curriculum projects cited in The Process of Education were examined. The materials of the following projects were examined in detail: the Physical Science Study Committee, the School Mathematics Study Group, the Biological Sciences Curriculum Study, the University of Illinois Committee on School Mathematics, and the University of Illinois Studies in Inquiry Training. In examining these studies the emphasis was on understanding their rationale.

Other sources of information were derived from a review of the literature dealing with the report of the Woods Hole Conference, the curriculum projects cited by the conference, disciplinary structure, and learning by discovery.

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[1] Ibid.

Method of Research

The research method of this study was that of survey, analysis, synthesis, and evaluation. Although there are some exceptions, the literature surveyed was limited to that published since 1950, since the proposal of the Woods Hole Conference was not made until 1959. However, research relevant to the specific curriculum projects cited by the conference was underway as early as 1956. The current research on learning by discovery dates from the early 1950's, although some important research was conducted prior to that time. These earlier studies have been included where they were clearly relevant to the present research.

The analysis of the literature centered around the tasks of identifying the rationale, principles, and main concepts of both disciplinary structure and learning by discovery. Both the logical basis and research supporting the proposal of the Woods Hole Conference were analyzed. In addition the basic assumptions underlying the proposal were identified and examined.

Since much of the information related to the proposal dealt with only a single aspect, it was necessary to synthesize the available data extensively. From this synthesis the implications of the proposal for curriculum design were developed. Also the evaluations were based upon the synthesis of numerous evaluative studies of specific aspects of the proposal.

The evaluative criteria were those found in the research literature. Although it was intended to evaluate disciplinary structure by the advantages claimed for it, this was not possible since no studies of these claims were located. The projects based upon disciplinary structure were evaluated by five criteria:

1. Student achievement
2. Reactions of students
3. Reactions of parents
4. Reactions of teachers
5. Reactions of subject-matter specialists.

Learning by discovery was evaluated by the advantages claimed for it.

Definition of Terms

A number of terms used in this study required further clarification. Both disciplinary structure and learning by discovery required such treatment. Each of them was clarified in the appropriate place in the analysis.

CHAPTER II

AN ANALYSIS OF THE RATIONALE OF EFFORTS TO IMPROVE THE CURRICULUM BY EMPHASIS ON DISCIPLINARY STRUCTURE

The purpose of this chapter is to analyze and describe the rationale of current efforts to improve the school curriculum by emphasizing the teaching of disciplinary structure. Specifically the analysis will attempt (1) to identify and describe what disciplinary structure is, (2) to identify and describe several examples of disciplinary structure, (3) to determine how the structure of a discipline is identified, (4) to identify and describe the functions or advantages claimed for teaching disciplinary structure, and (5) to identify some of the assumptions which underlie the use of disciplinary structure as a basis for curriculum design.

An analysis of the curriculum design utilized by projects based on disciplinary structure is not included as part of the present chapter. This analysis is presented in the following chapter which presents a detailed examination of three such projects.

The Content Being Analyzed

As used throughout this study the concept of disciplinary structure is restricted to its meaning and functioning as found and illustrated in the report of the Woods Hole Conference[1] and in those curriculum projects which are cited in the report as examples of disciplinary structure. The projects cited by name are the School Mathematics Study Group, the University of Illinois Committee on School Mathematics, the University of Illinois Arithmetic Project, the Minnesota School Mathematics Center, the Biological Sciences Curriculum Study, the Physical Science Study Committee, and the Commission on Mathematics.[2]

A third source of information for the analysis consists of articles and books in the professional literature on education which describe or comment on the work of the Woods Hole Conference.

Identification and Description of Disciplinary Structure

The need for a clear and precise description of disciplinary structure is evident from a review of the reactions found in the professional literature to the report of the Woods Hole Conference. In a book review of the report the comment is made that "nowhere in the book is the term [disciplinary structure] adequately explicated."[1] In a similar vein Miel comments that "there is no general agreement on what a discipline is."[2]

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[1] Jerome S. Bruner, The Process of Education. Cambridge, Mass.: Harvard University Press, 1960.

[2] Ibid., pp. x and 2. This list is believed to contain two errors. All efforts to locate information about the Minnesota School Mathematics Center have failed. It is believed that the reference was intended to be to the Minnesota National Laboratories, a testing program for the evaluation of the School Mathematics Study Group. The second error concerns the nature of the Commission on Mathematics. This commission is not a curriculum project. It is an agency of the College Entrance Examination Board which made recommendations for the improvement of mathematics education.

Even a rapid reading of The Process of Education does, however, provide some insight into what is meant by disciplinary structure. The following quotation reveals, for instance, that there is a fundamental relationship between the structure of a subject and a discipline: "What are the implications of emphasizing the structure of a subject, be it mathematics or history--emphasizing it in a way that seeks to give a student as quickly as possible a sense of the fundamental ideas of a discipline?"[3] As is indicated by the quotation the report of the Woods Hole Conference uses disciplinary structure interchangeably with subject matter structure. In describing the curriculum projects based upon disciplinary structure, the report states that "the main object of this work has been to present subject matter effectively."[4] A more precise understanding of disciplinary structure can be obtained by determining what is meant by "this work." Specifically it consists of the new school courses prepared by such groups as the Physical Science Study Committee, the School Mathematics Study Group, and the Biological Sciences Curriculum Study. The subject matter of these groups are respectively physics, mathematics, and biology. These three areas of subject matter are, of course, commonly found in the school curriculum. In fact, the work of these groups consists of the reworking or reorganizing of these standard school subjects. Thus subject matter here refers to what is taught in these courses.

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[1] Elmer Eason and Charles H. Heimler, "A Keystone Concept with a Resolute Ring." Phi Delta Kappan 43:40; October 1961.

[2] Alice Miel, "Knowledge and the Curriculum" New Insights into the Curriculum. 1963 Yearbook. Washington, D. C.: The Association for Supervision and Curriculum Development, a Department of the National Education Association, 1963. Chapter 4, p. 80.

[3] Bruner, p. 3.

[4] Ibid., p. 2.

Other uses of subject matter are related to structure.[1] It is apparent from numerous examples that the report uses subject matter and subject as synonyms of each other, for no distinction could be found between the structure of subject matter and the structure of a subject.[2]

The terms subject matter and subject are, however, restricted to certain courses offered in school. No mention is made of courses such as shop, homemaking, physical education and the like. Instead the report dwells on such courses as physics, mathematics, English, social studies, biology, chemistry, and other courses commonly considered as academic or intellectual subjects. This leads to consideration of the question of what determines the nature of the subjects relevant to the report of the Woods Hole Conference.

The key to the answer is provided early in the report. "Strange as it may seem, this [the Woods Hole Conference] was the first time psychologists had been brought together with leading scientists to discuss the problems involved in teaching their various disciplines."[1] From this it is evident that the subjects of interest to the Conference are those which are related to the disciplines. Thus the problem now arises as to what a discipline is, at least in terms of its meaning to the members of the Conference.

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[1] Ibid., pp. 6, 18, and 19.

[2] See pages 6 and 18 of the report for evidence of this.

Perhaps the clearest insight into what is meant by a discipline is provided by the following statement from the report of the Woods Hole Conference. "There has been an unprecedented participation in curriculum development by university scholars and scientists, men distinguished for their work at the frontiers of their respective disciplines."[2] Clearly indicated here is the idea that a discipline is a field of study pursued by a college or university scholar or scientist. This concept of discipline is clearly appropriate to two other quotations which also identify the relationship between a discipline and its affiliated school subjects:

> There is a continuity between what a scholar does on the forefront of his discipline and what a child does in approaching it for the first time.[3]
>
> The experience of the past several years has taught at least one important lesson about the design of a curriculum that is true to the underlying structure of its subject matter. It is that the best minds in any particular discipline must be put to work on the task.[4]

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[1] Bruner, p. ix.

[2] Ibid., p. 1.

[3] Ibid., p. 28.

[4] Ibid., p. 19.

Both quotations indicate that a school subject may be a simplified version of the disciplines which the scholars and scientists themselves study. In any event, it is evident that the report of the Woods Hole Conference proposes that the relationship between the disciplines and school subjects be very close. So close, in fact, that the school subjects should be structured according to their respective disciplines. This is exactly how the new curriculum projects cited in The Process of Education have been organized.

The report of the Woods Hole Conference identifies another characteristic of a discipline, its working attitudes. These attitudes, according to the report, are concerned with such matters as methods of inquiry, hunches, and problem solving. "To instill such attitudes by teaching requires something more than the mere presentation of fundamental ideas."[1]

It was felt that learning by discovery would help students to adopt the working attitudes of a discipline:

> Just what it takes to bring off such teaching is something on which a great deal of research is needed, but it would seem that an important ingredient is a sense of excitement about discovery--discovery of regularities of previously unrecognized relations and similarities between ideas.[2]

Consequently, learning by discovery was suggested as a means of teaching the structure of a discipline. The report makes special mention of the use of discovery methods of instruction in the material of the

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[1] Ibid., p. 20.

[2] Ibid.

University of Illinois Committee on School Mathematics. In describing this work Bruner reports that those persons associated with the project "have been active in devising methods that permit a student to discover for himself the generalization that lies behind a particular mathematical operation."[1]

Both the mathematicians and scientists were enthusiastic about the utilization of discovery methods to teach both the structure and proper attitudes toward their respective fields of study. Bruner himself feels that discovery methods may also be effectively used to teach the structure and attitudes of other less formalized subjects. In order to discuss adequately learning by discovery two chapters of this study have been devoted to the topic. Chapter V presents an analysis of learning by discovery, while Chapter VI evaluates the effectiveness of methods of instruction for discovery.

The report of the Woods Hole Conference provides little additional insight into the nature of a discipline. At no point does the report address itself to a consideration of the philosophical concepts of a discipline. Instead it confines itself to the tasks of outlining the relationships between the disciplines and school subjects. It seems safe to conclude that the report uses the term discipline in reference to certain school subjects and not in regard to the philosophic aspects of ontology and epistemology. Indeed, the fact that the disciplines are closely related to certain school subjects explains the importance of the disciplines to curriculum design and construction.

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[1] Ibid., p. 21.

From the above discussion three observations about a discipline which are germane to the work of the Woods Hole Conference can be identified:

1. A discipline is a field of study organized and pursued by college or university scholars and scientists.

2. A discipline serves as the basis for organizing a school subject that is derived from the discipline.

3. A discipline has certain working attitudes about its methods of investigation which will be taught in a school subject derived from a discipline.

At this point attention may be directed toward clarifying the term structure. At no point in the report of the Woods Hole Conference is a specific definition of structure given. Rather, an attempt is made to explain what is meant by structure through examples and statements of characteristics.

In the section of the report which purports to define structure the importance of organization as a characteristic of structure is clearly stated. "Grasping the structure of a subject is understanding it in a way that permits many other things to be related to it meaningfully. To learn structure, in short, is to learn how things are related."[1] Therefore, the organization of information into some form of pattern is an essential element of structure, for the organization provides the means by which new material and information are related to that which is already known.

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[1] Ibid., p. 7.

Structure, then, supplies the framework to which additional information is to be related.

A second essential characteristic of structure is that it consists of the principles of a subject. The close relationship among structure, principles, and subject matter is indicated by the following statement: "The curriculum of a subject should be determined by the most fundamental understanding that can be achieved of the underlying principles that give structure to that subject."[1] From this quotation it is apparent that the principles of a subject account for its structure. Taking into account the previously indicated quality of structure, its organization or relatedness, structure may be conceived of as the organized pattern of the principles of a subject. It follows, then, that in speaking of structure in relation to school curriculum, structure refers to the organized principles of a school subject.

Examples of Disciplinary Structure

Rather than attempting to further define structure, the report of the Woods Hole Conference lists several examples of structure to help clarify its meaning and use.

The first example shows that structure is used by the pre-school child in learning his native language. Attention is also called to the fact that structure may be mastered without the learner being conscious of the structural basis of what he has learned.

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[1] Ibid., p. 31.

> The often unconscious nature of learning structures is perhaps best illustrated in learning one's native language. Having grasped the subtle structure of a sentence, the child very rapidly learns to generate many other sentences based on this model though different in content from the original sentence learned. And having mastered the rules for transforming sentences without altering their meaning--"The dog bit the man" and "The man was bitten by the dog"--the child is able to vary his sentences much more widely. Yet, while young children are able to use the structural rules of English, they are certainly not able to say what the rules are.[1]

Although the structural rules of English, in this case probably the knowledge of word order, are not specifically identified, the quotation does indicate that structure provides a basis for relating information.

A second example illustrates the role of structure in mathematical relationships:

> Algebra is a way of arranging knowns and unknowns in equations so that the unknowns are made knowable. The three fundamentals involved in working with these equations are commutation, distribution, and association. Once a student grasps the ideas embodied by these three fundamentals, he is in a position to recognize wherein "new" equations to be solved are not new at all, but variants on a familiar theme.[2]

Actually, the application of the three fundamentals listed above is even wider than is indicated, for they also compose part of the structure of the earlier mathematics of addition and multiplication.

From the examples so far provided, it might appear that structure is limited to subjects such as mathematics, science, and similar subjects characterized by their objectivity and logic. Bruner, the chairman of the conference, denies this, although he acknowledges that the new curriculum projects emphasizing structure are confined to the fields of mathematics and science. This, however, may be attributed in part to the fact that federal support has also been restricted primarily to these areas.

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[1] Ibid., p. 8.

[2] Ibid., pp. 7-8.

Bruner, in fact, provides examples of the use of structure in art and literature. There is, however, a difference in the nature of the structure used in mathematics and science and that used in art and literature.

> The underlying principle that gives one the power to use literature and the arts in one's thinking is not of the order of a generic condensation of knowledge [as it is in mathematics and science]. Rather it is metaphoric in nature, and perhaps the best way of describing this class of principles is to call them guiding myths.[1]

To clarify his meaning still further Bruner takes as an example of such a guiding myth the story of Perseus slaying the Medusa. Since anyone who looked at the Medusa would be turned to stone, Perseus was able to see to kill the Medusa by observing her reflection on his polished shield. Bruner explains the metaphoric meaning thus:

> The polished shield might symbolize all of the devices by which we are able to take action against evil without becoming contaminated by it. The law suggested itself as one such device, enabling us to act against those who trespassed against morality without ourselves having to trespass in our action.[2]

It is through the metaphoric interpretation of art and literature that structure may be uncovered. And by grasping this structure of art and literature, man is able to relate these important aspects of life to himself and his behavior. For Bruner affirms "that a grasp of the basic plights through the basic myths of art and literature provides the organizing principle by which knowledge of the human condition is rendered into a form that makes thinking possible, by which we go beyond learning to the use of knowledge."[1] Bruner expands on his concept of the metaphoric nature of structure in his recent book On Knowing.[2]

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[1] Jerome S. Bruner, "Learning and Thinking." Harvard Educational Review 29:185; Summer 1959.

[2] Ibid., p. 186.

The examples of structure reviewed above aid in further clarifying the meaning of structure. They show, for example, that structure cannot be restricted to the logical organization of the principles of a subject as some authorities indicate. Hughes, for example, although his general concept of structure is accurate, errs in limiting structure to a form of logical organization:

> It is this ordering which Bruner has called "Subject structure" which may be described as an ordering of a given body of subject-matter in terms of those concepts which have the greatest logical organizing power, i.e., are capable of explaining the widest range of phenomena, of relating the largest amount of subject-matter and which exhibit the greatest generality and inclusiveness.[3]

The last example given shows that there are other means of organizing the concepts or principles of a subject besides logic.

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[1] Ibid.

[2] Jerome S. Bruner, On Knowing. Cambridge, Mass.: Belknap Press of Harvard University Press, 1962.

[3] Phillip Hughes, "Decisions and Curriculum Design." Educational Theory 12:191; July 1962.

From the examples studied it is apparent that structure is not limited to science and mathematics or to specific levels of instruction. In the mathematics and sciences structure is characterized by its generic condensation of the field or subject. In the arts and literature it has the metaphoric nature of a guiding myth. In either case the definition of structure as the organized principles of a school subject still holds true. Nothing so far uncovered invalidates this definition.

In terms of instructional levels, examples were provided from several grade levels. Therefore, it appears that disciplinary structure may be taught at all levels of instruction, for knowledge of structure is an essential ingredient in promoting effective learning for both the preschool child and the advanced scholar working at the frontier of his chosen field of study. Indeed, it is this very pervasiveness of structure that has been instrumental in leading the Woods Hole Conference to proclaim "that the foundations of any subject may be taught to anybody at any age in some form,"[1] a truly sweeping generalization which shall be the subject of further comment later in this study.

How Disciplinary Structure Is Identified

Up to this point this chapter has confined itself to attempting to derive a clear and precise understanding of what is meant by disciplinary structure. Although this section moves to the consideration of another facet of structure, it should provide additional insight into the meaning and nature of disciplinary structure.

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[1] Bruner, The Process of Education, p. 12.

Although the report of the Woods Hole Conference is somewhat unclear about what is meant by disciplinary structure, it leaves no doubt about how the structure of a discipline is to be identified.

> The experience of the past several years has taught at least one important lesson about the design of a curriculum that is true to the underlying structure of its subject matter. It is that the best minds in any particular discipline must be put to work on the task. The decision as to what should be taught in American history to elementary school children or what should be taught in arithmetic is a decision that can best be reached with the aid of those with a high degree of vision and competence in each of these fields.[1]

In short, the scholars will determine what will be taught in each of the subject fields. Specifically, they will identify the structures of the disciplines. The central role of the activity of the scholars is a vital one according to the report of the Woods Hole Conference. When the scholars have been separated from the schools "school programs have often dealt inadequately or incorrectly with contemporary knowledge, and we have not reaped the benefits that might have come from a joining of the efforts of eminent scholars, wise and skillful teachers, and those trained in the fields related to teaching and learning."[2]

It is to overcome such obvious shortcomings as these that the scholars are enlisted to aid in the planning of the school curriculum. Also it would probably be impossible for anyone except the scholars to identify the structure of their disciplines.

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[1] Ibid., p. 19.

[2] Ibid., p. 3.

> Designing curricula in a way that reflects the basic structure of a field of knowledge requires the most fundamental understanding of that field. It is a task that cannot be carried out without the active participation of the ablest scholars and scientists. The experience of the past several years has shown that such scholars and scientists, working in conjunction with experienced teachers and students of child development, can prepare curricula of the sort we have been considering.[1]

Thus the method of identifying the structure of a discipline is clearly indicated; the university scholars and scientists define the structure of their respective disciplines.

Advantages Claimed for Teaching the Structure of a Discipline

The rationale for basing curriculum design on disciplinary structure is justified in part by the advantages that are claimed for teaching the structure of a discipline. If, then, structure is to dominate curriculum design, what are its particular values in promoting learning and instruction? The Woods Hole Conference identified four specific advantages of teaching disciplinary structure:

1. It makes a subject more comprehensible.
2. It reduces memory loss.
3. It promotes general transfer of learning.
4. It helps narrow the gap between elementary and advanced knowledge.

In the remainder of this section each of these advantages is discussed in turn.

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[1] *Ibid.*, p. 32.

How does understanding the structure of a subject make the subject more comprehensible? Comprehension is increased because knowledge of structure provides a framework to which otherwise isolated and unrelated facts and information can be assimilated. Structure provides a frame of reference against which newly acquired material can be compared and contrasted. In this sense, structure affords an organized pattern to which subsequent information can be quickly and efficiently related. For this reason teaching the structure of a subject "is probably even more valuable for the less able student than for the gifted one, for it is the former rather than the latter who is most easily thrown off the track by poor teaching."[1]

A second function of structure is to reduce memory loss. "Perhaps the most basic thing that can be said about human memory, after a century of intensive research, is that unless detail is placed into a structured pattern, it is rapidly forgotten."[2] Structure promotes memory by placing details into a simplified organization of principles which greatly increases the chances of recall in that the memory of one aspect of the pattern may quickly lead to recall of other related elements. It is the close interrelationships that exist between the parts and the whole that make this possible. And this, of course, is exactly the purpose of structuring a subject. "Subject matter presented so as to emphasize its structure will perforce be of that generative kind that permits reconstruction of the details or, at very least, prepares a place into which the details, when encountered, can be put."[1]

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[1] Ibid., p. 9.

[2] Ibid., p. 24.

Knowledge of structure also appears to enhance the possibility of transfer of training or the ability to generalize widely. "The teaching and learning of structure, rather than simply the mastery of facts and techniques, is at the center of the classic problem of transfer."[2] Structure, then, promotes the learning and transfer of principles.

> That is to say, in order for a person to be able to recognize the applicability or inapplicability of an idea to a new situation and to broaden his learning thereby, he must have clearly in mind the general nature of the phenomenon with which he is dealing. The more fundamental or basic is the idea he has learned, almost by definition, the greater will be its breadth of applicability to new problems.[3]

The fourth advantage of learning the structure of subject matter is that the material will be kept up to date. As the scholars at the forefront of their fields reorganize and add to a subject's structure, the new material will also be passed on to the schools with a minimum of delay. This is true because these same scholars and scientists are continuously defining the structure that the schools will teach. Therefore, the gap between knowledge at the frontier of a field and that taught in the school will be narrowed.

> Part of the difficulty now found in the progression from primary school through high school to college is that material learned earlier is either out of date or misleading by virtue of its lagging too far

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[1] Bruner, On Knowing, p. 121.

[2] Bruner, The Process of Education, p. 12.

[3] Ibid., p. 18.

behind developments in a field. This gap can be reduced by the kind of emphasis set forth in the preceding discussion.[1]

These, then, are the four special advantages claimed for teaching the structure of a discipline. Since the purpose of this chapter is to analyze and describe the rationale of teaching disciplinary structure, no attempt will be made to determine whether or not such advantages are forthcoming when structure is taught. This evaluation is deferred until a later chapter. It is proper, however, to list several theoretical disadvantages of not teaching the structure of a subject. These are included here because of their relationship to the advantages claimed by the proponents of teaching disciplinary structure.

The report of the Woods Hole Conference contains the following statement of the disadvantages of not basing curriculum design on structure:

> Teaching specific topics or skills without making clear their context in the broader fundamental structure of a field of knowledge is uneconomical in several deep senses. In the first place, such teaching makes it exceedingly difficult for the student to generalize from what he has learned to what he will encounter later. In the second place, learning that has fallen short of a grasp of general principles has little reward in terms of intellectual excitement. The best way to create interest in a subject is to render it worth knowing, which means to make the knowledge gained usable in one's thinking beyond the situation in which the learning has occurred. Third, knowledge one has acquired without sufficient structure to tie it together is knowledge that is likely to be forgotten.[2]

The study of the disadvantages listed above shows that each of them is, in effect, an inverse statement of the previously discussed advantages of teaching disciplinary structure. In any event nothing new has been added to the reasons why structure should be taught.

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[1] Ibid., p. 26.

[2] Ibid., p. 31.

Identification of Assumptions

The concept of disciplinary structure as a basis for curriculum design is founded upon two groups of assumptions. The first group of assumptions is concerned with the nature of knowledge, the second with the nature of learning. One critic of the new curriculum studies using structure as the basis for design makes this observation: "Consciously or unconsciously, and more or less consistently, the studies reflect emerging, though not yet clearly enunciated, concepts of the nature of man and how he learns and the nature of knowledge and its uses."[1] In the following paragraphs these two groups of assumptions will be presented in an attempt to explicate their significance for teaching the structure of a discipline.

The report of the Woods Hole Conference makes no specific mention of the nature of knowledge. Bruner, the chairman of the conference, however, has written elsewhere about the relationship between the concept of subject-matter structure and the nature of knowledge:

> The issue of subject matter in education can be resolved only by reference to one's view of the nature of knowledge. Knowledge is a model we construct to give meaning and structure to regularities in experience. The organizing ideas of any body of knowledge are inventions for rendering experience economical and connected. We invent concepts such as force in physics, the bond in chemistry,

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[1] Francis S. Chase, "Some Effects of Current Curriculum Projects on Educational Policy and Practice." School Review 70:132; Spring 1962.

motives in psychology, style in literature as means to the end of comprehension.[1]

The extent to which the other members of the Woods Hole Conference might agree or disagree with the ideas presented above is unknown. There is evidence, however, that some aspects of these ideas are shared, at least in part, by some of the scientists working on the new projects. Joseph J. Schwab, of the Biological Sciences Curriculum Study, is especially concerned about having students realize that knowledge, especially scientific knowledge, is a product of man's mind and as such is subject to error and subsequent modification.[2]

Certainly both Bruner and Schwab would agree that knowledge changes as man adds to and reconstructs his ideas. At least some kinds of knowledge, then, would be of a dynamic, changing nature, not static and absolute.

Chase reports that the new curriculum studies are based upon a dynamic and changing view of knowledge. "With regard to a theory of knowledge, the curriculum studies are grounded in a view that rejects the notion of specific items of information to be learned and the view that extension of knowledge occurs through a simple process of accretion."[3] Chase feels that the new projects present knowledge as a pattern of related concepts and principles that give structure to a field of knowledge.

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[1] On Knowing, p. 120.

[2] See Schwab's article, "Some Reflections on Science Education." BSCS Newsletter 9:8-9; September 1961.

[3] Chase, p. 134.

In addition these structured concepts and principles serve "as perspectives through which to view phenomena--perspectives moreover that are recognized as partial and temporary in nature and, therefore, to be supplemented and/or replaced in time by other perspectives."[1]

To assert that all knowledge has a dynamic, changing nature, however, may be a gross oversimplification. Chase and Schwab are both concerned with the knowledge of science and mathematics. Whether or not the knowledge of other subject-matter areas, such as literature and art, is characterized by the same nature is open to question. Bruner apparently feels that even knowledge in these areas is a creation of man and as such must be viewed as dynamic, not permanent. Yet, it must be recalled that Bruner has stated that the nature of structure in mathematics and science is based on the generic condensation of knowledge while the structure of art and literature is of a metaphoric nature. This difference in the structure of the two groups of knowledge raises questions about the similarity of their respective natures. Although it is not the purpose of this study to attempt to resolve such questions, it is well to bear in mind that different bodies of knowledge may have different natures. Nevertheless, all knowledge is subject to change in some respects, for the work of the scholars and scientists is concerned with the continuous improvement and expansion of knowledge, in itself a type of change.

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[1] Ibid.

A second assumption about the nature of knowledge is that it must be structured to be of maximum benefit to man. This is the crux of the relationship between knowledge and structure. It is structured knowledge that promotes the four advantages cited by the Woods Hole Conference in support for teaching disciplinary structure. Structured knowledge increases comprehension, aids memory, promotes transfer of learning, and reduces the gap between elementary and advanced knowledge. Unstructured knowledge, on the other hand, fails to possess any of these advantages.

Another assumption of the Woods Hole Conference is that knowledge may be most effectively taught by dividing it into certain disciplines and that the knowledge in each of these disciplines has its own structure. It is because each of the disciplines has its own structure that knowledge is best taught by observing subject-matter boundaries. If two or more subjects were taught together, then, the structure of neither could be effectively presented. Therefore, the advantages claimed for teaching structure would not be realized.

Next to be considered are the assumptions made about the nature of learning.

Basic to the Woods Hole Conference's concept of the nature of learning is the belief "that any subject can be taught effectively in some intellectually honest form to any child at any stage of development."[1] This assertion rests upon several basic assumptions. The report of the conference states that the above belief "is premised on the considered judgment that any idea can be represented honestly and usefully in the thought forms of children of school age, and that these first representations can later be made more powerful and precise the more easily by virtue of this early learning."[1]

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[1] Bruner, The Process of Education, p. 33.

The conference's thinking is heavily influenced by the research on children's learning by Inhelder and Piaget. Chapter 3, "Readiness for Learning," of The Process of Education is devoted to outlining the means by which the disciplinary structure may be effectively taught to children of various ages. The report asserts that there are three basic considerations or ideas that must be taken into account in effectively teaching disciplinary structure.

First to be considered is the process of intellectual development in children. Accepting as fact the idea that children have characteristic stages of viewing the world, the conference asserts that "the task of teaching a subject to a child at any particular age is one of representing the structure of that subject in terms of the child's way of viewing things."[2] Thus to teach disciplinary structure it is necessary to translate the formal language of the scientists into the language and thought patterns of the learners.

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[1] Ibid.

[2] Ibid., p. 33.

It is from the research of Inhelder and Piaget[1] that the language and thought patterns of the child are to be identified. The conference accepts the three stages outlined by Piaget: (1) preoperational, (2) concrete operations, and (3) formal operations. Depending upon which stage the learner is in, the structure of the subject may be taught by translating it into the proper intellectual stage. This, however, is not the most important aspect of teaching structure. The main aspect is "that the child be helped to pass progressively from concrete thinking to the utilization of more conceptually adequate modes of thought."[2] In other words, the primary concern is to help the child pass through the stage of intellectual development as rapidly as possible. This, according to the report of the Woods Hole Conference, is accomplished by the proper translation of the structure of a subject.

The task of translating the structure identified by the scholars and scientists is assigned to the teachers and psychologists. This is obviously the function that they were expected to serve in the preparation of the materials for the projects mentioned in The Process of Education. Their role was one of matching the structure of the subjects to the interests and abilities of the students. It follows, then, that the work of the teachers and psychologists is to be dominated by the disciplinary structure.

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[1] For a detailed explanation of this research see Bärbel Inhelder and Jean Piaget, The Growth of Logical Thinking from Childhood to Adolescence. New York: Basic Books, Inc., 1958.

[2] Bruner, The Process of Education, p. 38.

The second basic consideration in teaching disciplinary structure is concerned with the act of learning. According to the conference, "learning a subject seems to involve three almost simultaneous processes":[1] (1) the acquisition of new information, (2) the transformation of information to make it pertinent to new situations, and (3) an evaluation of the transformed information to determine how adequately it meets the demands of the new situation.

These three processes normally constitute a learning episode. In order to adjust the learning episode to the abilities and interests of the students, three techniques are commonly used: (1) adjusting the length of the episode, (2) using extrinsic rewards, and (3) "dramatizing the shock of recognition of what the material means when fully understood."[2] The teaching of structure has important implications in relation to these three aspects of learning episodes. Since structure is characterized by its ability to develop the relationships among various aspects of a subject, it does dramatize the meaning of the material. This occurs as the subject becomes more comprehensible to the learner. In addition the use of discovery learning also introduces a dramatic element when insight occurs.

Learning by discovery and the teaching of structure provide intrinsic rather than extrinsic rewards for learning. The conference feels that heightened awareness and understanding which result from the teaching of structure will provide intrinsic motivation for learning. Translating the structure into the appropriate thought patterns and language of the learner also insures that interest and motivation will remain high.

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[1] Ibid., p. 48.

[2] Ibid., p. 49.

The conference also believes "that the more one has a sense of the structure of a subject, the more densely packed and longer a learning episode one can get through without fatigue."[1] This is true because teaching the structure of a subject provides a means by which a learner is able to relate new material to what he already knows. Since he is aware of these relationships, his learning is more efficient and he experiences less fatigue.

The final basic consideration in teaching disciplinary structure is the progressive development of basic ideas introduced earlier in simplified form. The spiral curriculum is the means advocated by the Woods Hole Conference for gradually introducing the ramifications and complexities associated with such ideas. Although structure is taught to the elementary school child, it is presented in a relatively simplified form. As the child advances in school these simplified ideas are revisited and the complexities are gradually introduced until the student understands the formal structure of the discipline.

Each of the three considerations described above constitutes part of the rationale behind the assumption that any child at any stage of intellectual development can be taught any subject in some intellectually honest form.

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[1] Ibid., p. 51.

The second major assumption about the nature of learning made by the Woods Hole Conference is "that intellectual activity anywhere is the same, whether at the frontier of knowledge or in a third-grade classroom."[1] Unlike the previous assumption there is little evidence one way or the other on this one. The conference arrived at this assumption by asserting that similar activities call forth similar intellectual processes no matter how much difference exists in the education and maturity of the individuals involved. The difference between the intellectual activities of the scholar and the school boy is one of degree, not kind. This leads to the conclusion that the "school boy learning physics is a physicist, and it is easier for him to learn physics behaving like a physicist than doing something else."[2]

The final assumption made about the nature of learning is that later, more complicated material is best learned by teaching it as a further ramification of the principles and concepts learned earlier. This, of course, is the basic idea of the spiral curriculum. The spiral curriculum, in turn, is a direct implementation of the utilization of disciplinary structure as the basis for curriculum design. For what one does in implementing the structural approach to curriculum design is to achieve articulation by having the basic ideas first presented in a simplified form, then at later dates new material is introduced which is incorporated into the simplified structure. It is assumed that the spiral curriculum provides the optimum opportunities for learning the structure of a discipline.

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[1] Ibid., p. 14.

[2] Ibid.

Summary

The concept of disciplinary structure examined in this chapter is the one outlined in The Process of Education. An analysis of the concept revealed that disciplinary structure consists of the organized principles of a school subject. In the case of science and mathematics, the structure is composed of generic condensations, while in art and literature the structure has a metaphoric nature.

The structure of a discipline is identified by the scholars and scientists in the field. Teachers and child psychologists are to assist the scholars and scientists in translating the structure of a discipline into the appropriate language and thought forms of the learners.

Four claims for the superiority of teaching the structure of a discipline were made by the Woods Hole Conference:

1. It makes a subject more comprehensible.
2. It reduces the extent of memory loss.
3. It promotes general transfer of learning.
4. It narrows the gap between elementary and advanced knowledge.

An analysis of disciplinary structure as the basis for curriculum design reveals that two sets of assumptions are basic to this point of view.

One set is concerned with the nature of knowledge; the other, with the nature of learning.

In regard to the nature of knowledge it is assumed:

1. All knowledge is subject to some degree of modification or change.

2. Knowledge must be structured to be of maximum benefit to man.

3. Knowledge can be most effectively taught by dividing it into disciplines, and each of the disciplines has its own structure.

In regard to the nature of learning it is assumed:

1. Any idea can be learned by any child at any stage of development if the idea is translated into the appropriate thought forms of the child.

2. Intellectual activity, and consequently the nature of learning, is basically the same everywhere, regardless of the education or the maturity level of the learner.

3. Learning is most efficient when the basic ideas or structure of a subject are revisited from time to time at successively higher levels.

CHAPTER III

AN ANALYSIS AND DESCRIPTION OF THREE PROJECTS THAT EMPHASIZE DISCIPLINARY STRUCTURE

The purpose of this chapter is to analyze and describe three projects based upon the disciplinary structure curriculum design approach outlined by the Woods Hole Conference. The three projects to be examined are the Physical Science Study Committee's course in physics, the School Mathematics Study Group's courses, and the Biological Sciences Curriculum Study's biology course.

Each of the above projects will be examined individually in an attempt to identify (1) the course organization and structure, and (2) the principles of content selection, sequence, and scope.

The three projects selected for analysis were chosen for three reasons. First, each of these projects, except the School Mathematics Study Group, has completed the development of its materials. The School Mathematics Study Group materials have also been completed except for those to be used in the elementary schools. Commercial editions of the completed materials of these projects have already been published or soon will be. Second, an extensive amount of information is available on each of the three projects. Numerous articles and reviews of all three projects are available in the professional literature. Finally, each of these three projects is mentioned by name in the report of the Woods Hole Conference as an exemplar of disciplinary structure curriculum design.

Since the existing projects based upon the disciplinary structure curriculum design approach are limited entirely to courses in mathematics and science, it was not possible to analyze and describe courses from the other subject matter areas.

Data for the analyses and descriptions of the three projects were gathered from two types of sources: (1) the texts, teacher's guides, and other materials prepared for the projects themselves, and (2) a review of the professional literature dealing with the projects.

Before beginning the analyses and descriptions of these proposals, attention is invited to the fact that thirteen of the thirty-four members of the Woods Hole Conference were affiliated with the three projects being examined. Three members of the conference were affiliated with the Biological Sciences Curriculum Study, four with the School Mathematics Study Group, and five with the Physical Science Study Committee. One member of the conference worked on two of the three projects.[1]

The order of the analyses and descriptions will be the Physical Science Study Committee, the School Mathematics Study Group, and the Biological Sciences Curriculum Study.

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[1] See Appendix A for a list of these members and their affiliation with the three projects being examined in this chapter.

Physical Science Study Committee (PSSC)

The work of PSSC began in 1956 at the Massachusetts Institute of Technology. The aims of the committee, which felt that high school students could master a higher level of physics than was generally provided, were threefold: "(1) to plan a course of study in which major developments of physics, up to the present time, are presented in a logical and integrated whole; (2) to present physics as an intellectual and cultural pursuit which is part of present-day human activity and achievement; and (3) to assist physics teachers, by means of various teaching aids, to carry out the proposed program."[1]

The development of a text was among the first activities the committee undertook. It was felt that this would be the best method for preparing and implementing the course of study. One hundred thirty-nine persons worked on the text: 84 were college affiliated, mostly physicists; 25 were secondary school teachers; the remaining 30 were school administrators and representatives of business, industry, or government. After undergoing three or four years of experimental use, the text was published commercially in 1960.[2]

Organization and Structure

The course is organized around the basic ideas and principles which form the structure of modern physics. Six considerations provide the structure of the course:

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[1] Francis L. Friedman, "The Physical Science Study: A Blueprint." Science Teacher 24:320; November 1957.

[2] Physical Science Study Committee, Physics. Boston: D. C. Heath and Co., 1960. 656 pp.

1. The unity of physical science
2. The observation of regularities which form the bases of Laws
3. The existence of many independent arguments to support a Law
4. The deduction of phenomena from Laws
5. The acceptance of the limitations of physical Laws
6. The use of models to provide explanatory background which can be subjected to investigation.

The recognition and acceptance of these six considerations led the committee to formulate a single unifying goal. "After considerable discussion, the committee agreed that physics would be more meaningful to the student and its unity would be stressed if the presentation of the subject matter were focused toward one goal, and that this goal ought to be the atomic picture of the universe."[1]

As the planning of the course continued, six principles served as guidelines for structuring the course:

> 1. The PSSC seeks to present physics as an intellectual activity, rather than a body of rules for the control or the manipulation of natural phenomena.
> 2. The PSSC seeks to reflect in its course the spirit of inquiry.
> 3. The course reflects, as much as possible, the world of physics as it appears to the professional physicist, for only in this manner is it likely to have any clear relevance to the student himself.
> 4. The PSSC course prefers to present the traditional subdivisions of physics as various aspects of a single discipline.

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[1] Physical Science Study Committee, "Physical Science Study Committee." Physics Today 10:28; March 1957.

5. The nature of the American school system makes it desirable to create a course which will be relatively independent of the order and content of the rest of the secondary school curriculum.

6. The most difficult decision which faced the PSSC at the outset of its work was the decision to omit from the course large areas of physics, and the selection of those areas which would be omitted.[1]

The structure and organization of the course were derived from the combination of the six considerations previously mentioned and the six principles stated above. From this combination the outline of the text was developed.

The text is divided into four parts. The first part is an introduction to the concepts of time, space, matter, and motion. The second part begins with the study of optical phenomena and ends with the study of the wave theory of light. The next part is concerned with mechanics and presents many of the traditional aspects of physics, including the laws of momentum, energy, and conservation. The last part introduces electricity and concludes with the structure of the atom.

The organization of the course reflects the structure that the physicists have identified. One of the most apparent changes from conventional courses is the emphasis on the abstract and theoretical nature of physics. The PSSC course is a study of the conceptual framework of modern physics. The focus of the course is on intellectual activity. Practical considerations, technology, and the like are almost entirely neglected.

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[1] Stephen White, "The Physical Science Study Committee: (3) The Planning and Structure of the Course." Contemporary Physics 2:41-43; October 1960.

Organizing a course according to disciplinary structure requires that the subject-matter specialists develop the course outline. Since the specialists are primarily interested in their own discipline, this results in a natural inclination to follow a separate subjects pattern of curriculum organization. Although the physicists claim that it is the nature of the American school system which creates the need to construct a physics course relatively independent of the rest of the school curriculum, this assertion is highly questionable. If the physicists believed that their discipline could be better taught in conjunction with other subjects, they would feel obligated to support such an approach. No one would deny that the traditional pattern in most schools is to teach physics as a separate subject, but there is every reason to believe that if the physicists have advocated a closer relationship between physics and other subjects, many educators would have lent their support. The call for greater integration of the various subjects has been actively sought by curriculum authorities for many years. There is no evidence that the physicists sought either the assistance or support of these curriculum authorities. Tradition and the lack of interest in integrating physics with other subjects stifled any efforts in this direction.

Another factor influencing the physicists to adopt the separate subjects pattern arises out of the nature of the structure of physics, or for that matter any other discipline. A course in English must parallel the structure of English. A course in history must, likewise, reflect the structure of history. And a course in physics must emulate the structure of physics. Implied in this is the idea that two or more subjects can be integrated, as far as disciplinary structure is concerned, only to the extent that the structures of the subjects themselves are similar. Integration on this basis is indeed possible and very likely desirable. However, little if any work has yet been undertaken to determine which subjects have sufficiently similar structures to permit their integration. Of course, it is commonly believed that such similarities of structure do exist among the several sciences, but so far no one has adequately identified the common elements of structure. This being the case, teaching structure requires the treatment of subjects separately from one another.

From the point of view of disciplinary structure these points of integration appear of a trivial nature. The physicists, for example, are aware of the relationship of their discipline to mathematics. Indeed, they have expressed alarm about the degree of abstractness characteristic of some of the newer mathematics projects, including the SMSG program. This complaint results from the attempt of the mathematicians to teach the structure of their discipline. According to some mathematicians mathematics as a tool of physics is only indirectly related to the structure of mathematics as a discipline. Facts like this further complicate the relationships among the various subjects.

There have been, however, some attempts to relate physics to other subjects. One activity of PSSC was to develop a series of monographs on different aspects of physics. According to the physicists these monographs will serve as a bridge between English and physics. "The monographs will provide history, biography, philosophy, and exposition which should be of auxiliary importance to teachers of English. The committee hopes to get physics teachers and English teachers to consider jointly the kinds of English activities which would make sense to both."[1]

Selection of Course Content

As was indicated above, the selection of course content is based on the structure identified by the physicists. To them falls the responsibility of determining what the course content will include.

The selection of content according to the structure of physics results in emphasizing abstractions. "To this end, the Physical Science Study Committee judged it wise to shift the emphasis in secondary school physics away from technology toward a deeper exploration of the basic ideas of physics and the nature of inquiries that can lead to these ideas."[2] Even a casual examination of the PSSC text reveals that technology has been almost entirely omitted. Topics such as radio, television, the internal combustion engine, and refrigeration have been replaced by the study of vectors, waves and light, molecular motion, and matter waves.

That emphasizing the abstract and theoretical concepts of physics is a natural result of teaching its structure seems reasonable. For structure itself is an abstraction created to organize the principles of a subject. Therefore, a curriculum based on disciplinary structure must be of an abstract nature.

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[1] Gilbert C. Finlay, "The Physical Science Study: What Are the Questions?" Science Teacher 24:328-29; November 1957.

[2] Gilbert C. Finlay, "The Physical Science Study Committee." School Review 70:66; Spring 1962.

Sequence of Course Content

The sequence of the course is determined by the logical unity of physics, which is also identified by the physicists. However, the logical unity of physics is not the only factor which influences sequence. This logical sequence must be presented in such a manner that it will have meaning for the students. The teachers who helped prepare the text were given the responsibility for relating the material to the students. In essence the teachers were responsible for "translating" the material into the thought patterns and habits of the students, a task which the Woods Hole Conference held to be the key to the effective teaching of structure. Sequence, then, was determined by the interrelationships that exist between the structure of the discipline and the fitting of this structure to the appropriate mental processes of the learner.

The structure, however, is of primary importance. It is first and foremost the structure that is to be learned; consequently, the sequence must, to a large degree, follow the logical order of the structure. The fitting of the structure to the thought patterns of the learner is merely a means to this end.

The logical unity and sequence of physics are presented by means of the spiral curriculum. By doing this "the intellectual thrust of the basic ideas is brought out sequentially through using those which are introduced early to illuminate other ideas in a chain that comprises an introductory view of the structure of physics."[1] This process reveals the relationships that exist between the earlier and later aspects of a subject. In general the spiral curriculum moves from simple ideas to those of a more complex nature. Sequence is not achieved by the simple assimilation of additional facts and information. "As an alternative to covering the various fields of physics at the same level, the course employs earlier material to clarify that which follows. For example, ideas about waves and particles recur, each time to be carried further in a higher synthesis of ideas."[2] Structure is the factor which ultimately determines the sequence of the course.

Grade placement of the course is for the senior year. The work was planned for the average twelfth-grade student who would normally be expected to take the traditional physics course.

Scope of Course Content

Teaching the structure of physics has had a decided effect on the scope of materials covered. In order to achieve its goals, the PSSC has had to curtail the variety and extent of topics covered.

> Achieving these aims in a one-year course meant that coverage of the field of physics had to be sharply restricted in favor of a deeper development of ideas that are central to a comprehension

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[1] *Ibid.*, pp. 65-66.

[2] Gilbert C. Finlay, "Secondary School Physics: The Physical Science Study Committee." *American Journal of Physics* 28:292; March 1960.

> of the fundamentals of contemporary physical thought. This deeper development meant carrying key concepts to higher levels than have been ordinarily reached in secondary school courses. Deeper development also meant a more extensive exploration of the substructure of experiment and thought that underlies the basic physical principles.[1]

Breadth of scope is sacrificed in order to achieve a deeper knowledge of the structure of the course. The emphasis is placed on those aspects of content which logically complement and expand the course structure. Depth study is provided for those ideas and concepts most closely related to structure. Almost all aspects of technology have been omitted in order to provide for greater depth.

Following this line of thought, breadth is subservient to depth. This emphasis on depth is an outgrowth of the spiral curriculum which, in turn, is a means of implementing the teaching of structure.

School Mathematics Study Group (SMSG)

Unlike the work of PSSC, SMSG is not limited to a single course for one grade level. The SMSG project covers grades four through twelve. Therefore, the description of its structure and organization will be in broader, more general terms. The specific details of each grade level will be presented in the section on sequence.

Before considering the curriculum design of SMSG a brief treatment of the background of the project is given. Influenced by the work of the PSSC a group of approximately thirty mathematicians met at the Massachusetts Institute of Technology on February 28 and March 1,

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[1] Finlay, School Review 70:65.

1958, to consider the prospects for undertaking a similar project in mathematics. Supported by the National Science Foundation and guided largely by the recommendations of the College Entrance Examination Board's Commission on Mathematics, the SMSG set out "to develop a curriculum and teaching materials based on the best available knowledge of mathematics, pedagogy, and the needs of our society."[1] The SMSG especially felt that there was a need to have the mathematics program of the schools reflect the new developments within the field of mathematics itself. Thus arose the interest in "modern mathematics."

In keeping with its goals and purposes, SMSG undertook the task of writing textbooks, believing that "if the busy and dedicated classroom teacher of mathematics is given a mathematically and pedagogically sound text, she will willingly, even eagerly, teach good mathematics to her students."[2] These texts were written by the joint effort of about 115 persons, including 65 mathematicians and 48 high school teachers. Over a period of two or three years these materials were tried out and revised several times. Some of them, especially those for the elementary grades, are still being tested and revised. Texts are now available for grades four through twelve.

Organization and Structure

As the SMSG materials were being prepared, the following five factors influenced the planning and organization of the proposed mathematics curriculum:

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[1] Edward G. Begle, "The School Mathematics Study Group." Mathematics Teacher 51:616; December 1958.

[2] Ibid., p. 618.

> 1. No one can predict exactly which mathematical skills will be important and useful in the future.
> 2. No one can predict exactly what career any particular student will choose when he leaves school.
> 3. Teaching which emphasizes understanding, insight, and imagination, without neglecting basic skills, is the best for all students, whatever their ability, and makes the best preparation for any vocation that uses mathematics.
> 4. An understanding of the role of mathematics in our society is essential for intelligent citizenship.
> 5. Any normal individual can appreciate some, at least, of the beauty and power of mathematics.[1]

Of special interest is the third factor. It appears to be an implication or, at least an assumption growing out of points one and two. Certainly it states the position of the SMSG on how best to react to the apparent dilemmas posed by the first two points. Also this third factor clearly identifies the basic viewpoint behind the SMSG approach to curriculum planning. From it many of the implications for organization, selection, sequence, and scope are readily apparent. The influence of this basic statement, actually an assumption, will be seen as the discussion and examination of the SMSG proposal develops.

Closely related to the five factors above are the following five aims and purposes of SMSG:

> 1. Giving the students a coherent structure which will make it easier to learn new things and remember the old
> 2. Emphasis on reasoning, beginning rather informally in elementary and junior high school, and leading to formal proof in algebra and geometry

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[1] Ibid., pp. 616-17.

3. Presenting mathematics as a creative art, rather than as a finished product, by giving students experience in discovery
4. Unifying subjects such as arithmetic, algebra, and geometry, which are traditionally taught separately
5. Clarifying the language of school mathematics, which is sloppy and confused in the conventional curriculum.[1]

Each of these purposes has a definite influence on the organization of the mathematics curriculum. The coherent structure mentioned refers to basic mathematical properties common to all known systems of mathematics. The number base is one such property. Other examples of the basic mathematical properties are closure, identity elements, and the commutative, associative, and distributive laws. All of these would have to be taught in a curriculum purporting to teach mathematical structure.

The second aim, emphasis on reasoning, is a reaction to the overemphasis of traditional mathematics on drill rather than understanding and logic. With the new emphasis on structure, reasoning and logic assume major importance as agents for developing relationships among various aspects of mathematical structure.

Teaching mathematics as a unified whole, the fourth aim, is one aspect of the teaching of structure. Structure, of course, consists of the organized fundamental ideas of a subject. Therefore, teaching structure is teaching the discipline as a unified whole.

The final aim, clarity of mathematical language, is also related to mathematical structure. This is done in order to sharpen the meaning and use of mathematical expressions. Precision of meaning enables the learner better to relate various mathematical ideas and concepts. One result of this is a better understanding of structure.

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[1] Paul C. Rosenbloom, "Mathematics K-14." Educational Leadership 19:360; March 1962.

Identification of the structure of the course rests with the mathematicians. Mathematical structure, like the structure of physics, emphasizes intellectual activity. SMSG material is noted for its abstract and theoretical qualities. Practical mathematics such as ratio, interest, and the like have been largely omitted from the SMSG texts. A check of the tables of contents and indices of these materials indicates that little attention is paid to these topics. Occasionally a short chapter will be devoted to some practical application of mathematics, but such matters are passed over rapidly. Indeed, many mathematicians today continuously stress the point that there is no direct relationship between mathematics and anything found in real life. In fact, it is asserted that mathematics is "a totally abstract, strictly logical and entirely independent discipline."[1] Such beliefs are held by some of the leading mathematicians today. The curriculum proposed by SMSG reflects such beliefs.

As was indicated earlier during the discussion of physics, the emphasis on the abstract nature of mathematics has caused concern less the application of mathematics to other subjects such as physics be omitted. At present SMSG has but one chapter in both its seventh and eighth grade texts which shows the application of mathematics to the sciences. SMSG has a strong bias toward the separate subjects pattern of curriculum organization.

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[1] Marshall H. Stone, "The Revolution in Mathematics." Liberal Education 47:304-27; May 1961.

Selection of Course Content

The selection of content is largely determined by the structure identified by the professional mathematicians. Selection is made according to the relationship of the content to the subject matter structure. The following list outlines the broad mathematical ideas which form the basis for selection of content:

> Structure [principles common to all mathematical systems]
> Operations and their inverses [addition, subtraction, multiplication, and division]
> Measurement [knowledge and use of standard units]
> Extensive use of graphical representation [number lines]
> Systems of numeration [concepts of number base]
> Properties of numbers, development of the real number system [closure; identity elements; associative, commutative, and distributive laws]
> Statistical inference, probability [chance]
> Sets--language and elementary theory [set notation]
> Logical deductions [especially of the "if-then" form]
> Valid generalizations [detection of mathematical patterns].[1]

Actually the other nine ideas are subdivisions of mathematical structure, the first item listed. They identify the main concepts that comprise the structure.

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[1] Kenneth E. Brown, "The Drive To Improve School Mathematics." The Revolution in School Mathematics. National Council of Teachers of Mathematics. Washington, D. C.: The Council, 1961. p. 22.

The study of these ideas, which provide the basis for content selection, reveals that SMSG does stress the abstract and theoretical aspects of mathematics. The same conclusion is reached after an examination is made of the tables of contents of the SMSG textbooks. Appendix B gives the tables of contents for all textbooks, grades four through twelve.

As is shown by the following quotation, the emphasis on abstraction, with its corresponding lack of application, causes the mathematicians little concern:

> We are not inclined to criticize a mathematics text on the grounds that it does not contain a host of illustrations showing mathematics applied to other fields. Valid applications of school mathematics, suitable for inclusion in a text, are hard to find. They must not be too contrived, too trivial, or too remote from the pupil's experience to be meaningful. It is probably better to provide applications in the form of pamphlets to be studied as supplementary units by pupils who have the interest, experience, and scientific background to profit from such study.[1]

These pamphlets have not yet been prepared. Students will have to request that application of mathematics to other fields be brought out by the classroom teachers, since no provision is made for teaching application as an integral part of the course content.

Another unique aspect of the content of SMSG is the inclusion of several new areas of mathematics referred to as modern mathematics. Among these topics are such items as linear programing, matrices, sets, topology, and probability and statistics.

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[1] National Council of Teachers of Mathematics, The Revolution in School Mathematics. Washington, D. C.: The Council, 1961. p. 83.

A third characteristic of the content is the change in the treatment of some of the traditional mathematics. Instead of teaching arithmetic, algebra, and geometry as entirely separate subjects, the SMSG approach is to present mathematics as a unified field of study. This is true in spite of the fact that the ninth and tenth grade texts treat algebra and geometry respectively. However, many of the principles of both of these topics are introduced much earlier. Elements of algebra and geometry are both found in the work being introduced in the elementary texts.

Another aspect of this change in treatment is indicated by the new approach used to teach certain of the traditional topics. Trigonometry is no longer taught as a means for solving problems related to triangles. Now it is studied so that the properties of trigonometric functions can be understood. Similarly logarithms are no longer studied as a tool for calculation. Modern computers are far better suited for this purpose. Logarithms are studied to emphasize the properties of the logarithmic functions.

The content selection, then, is made by the professional mathematicians as they identify the structure of mathematics. Teaching this structure results in the selection of content which is characterized by the following three qualities:

1. The abstract and theoretical properties of mathematics is stressed.

2. Material is drawn from the newer areas of mathematics, and a different treatment is made of many aspects of traditional mathematics.

3. Mathematics is treated as a unified field of study or discipline rather than as various isolated topics such as algebra, geometry, arithmetic, and the like.

Each of these qualities is a direct implication of teaching the structure. Other factors also influence the selection of content, but the three listed above are necessary complements to emphasizing structure.

Sequence of Content

The SMSG sequence follows the spiral approach characteristic of the PSSC. Concepts introduced earlier are repeated later, gradually assuming broader and deeper meaning with each recurrence. Since the SMSG texts cover grades four through twelve, greater possibilities for developing more fully the spiral approach to curriculum sequence exists than was the case with the PSSC materials which cover only grade twelve. These possibilities are shown in Table 1, which traces the spiral pattern of three SMSG topics: sets, the operations, and geometry. All three topics are first introduced in grade four, the earliest grade for which SMSG materials have been prepared. Although Table 1 indicates that the topics are no longer taught after certain grade levels, it must not be assumed that the topics are no longer used or studied. Quite the contrary is true. The topics retain their importance, being subsumed into more advanced material. In this sense the topics play a continuous role in further mathematical study.

Because SMSG developed materials for several grade levels, it was able to utilize more fully the spiral curriculum for sequence development. However, the present pattern of sequence is subject to modification

TABLE 1

SMSG SEQUENCE DEVELOPMENT OF THREE TOPICS

Grade	Chapter	Title
		Topic I--Sets
4	1	Concept of sets
4	5	Sets of points
6	10	Sets and circles
9	1	Sets and the number line
9	13	Truth sets of open sentences
10	2	Sets, real numbers and lines
10	14	Characterization of sets: constructions
		Topic II--Operations
4	3	Properties and techniques of addition and subtraction, I
4	4	Properties of multiplication and division
4	6	Properties and techniques of addition and subtraction, II
4	7	Techniques of multiplication and division
5	3	Extending multiplication and division
5	5	Addition and subtraction of fractional numbers
6	2	Multiplication of fractional numbers
6	6	Division of fractional numbers
9	6	Properties of addition
9	7	Properties of multiplication
9	9	Subtraction and division for real numbers
		Topic III--Geometry
4	8	Recognition of common geometric figures
5	4	Congruence of geometric figures
5	6	Measurement of angles
5	7	Area

TABLE 1--Continued

Grade	Chapter	Title
6	3	Side-angle relationships of triangles
6	7	Volume
6	10	Sets and circles
7	4	Nonmetric geometry
7	8	Area, volume, weight, and time
7	10	Parallelograms, triangles, and right prisms
7	11	Circles
8	4	Constructions, congruent triangles, and the Pythagorean property
8	9	Similar triangles and variation
8	10	Nonmetric geometry
8	11	Volumes and surface areas
8	12	The sphere
10	1-17	(The entire course is on geometry)
11	2	An introduction to coordinate geometry in the plane
12-1[a]	3	Tangents to graphs of polynomial functions
12-1[a]	5	Circular functions
12-2[a]	4	Representation of column matrices as geometric vectors
12-2[a]	5	Transformations of the plane

[a] Number following 12 indicates first or second semester.

and change. Since SMSG texts for the secondary level were planned before any work was attempted at the elementary level, the present sequential organization is not as well developed as possible.

Like PSSC, SMSG follows the logical patterns of sequence that are identified by the subject-matter specialists. The classroom teachers are asked to "translate" this logical structure into the appropriate thought forms and patterns of the students. In these respects the planning of sequence of the two projects is identical.

One unique feature of the SMSG texts is the inclusion of a suggested time schedule to be followed by the teachers. The teachers are cautioned to stay on schedule so that all the material can be covered within the alloted time. Coverage of all materials is essential to a course based on disciplinary structure unless some comparatively unrelated and isolated items are presented. These, of course, may be eliminated without harm to sequence. But the items basic to structure, and this should include most items, must be taught if the students are to be ready for the next unit of work.

Scope of Content

Some idea of the scope of the SMSG has previously been given in the sections on content selection and sequence. Scope is determined by the requirements for teaching the structure. Like PSSC, SMSG sacrifices breadth of scope in order to achieve more depth. Nevertheless, the scope of SMSG has been extended beyond traditional mathematics courses in an effort to up-date the content. Modern mathematics accounts for the expansion of breadth.

On the other hand much material formerly found in mathematics courses has been eliminated. Missing from SMSG materials are extended treatments of application, although there is still some material concerned with interest, ratio, and proportion. Most of the application has been eliminated in order to provide more time for the study of the abstract nature of mathematics. Since knowledge of the abstract structure of mathematics is the central purpose of SMSG, the scope of the courses reflects this purpose.

Biological Science Curriculum Study (BSCS)

An outgrowth of the work of the American Institute of Biological Sciences, the Biological Sciences Curriculum Study was organized in February, 1959, for the purpose of improving education in biology. Up to the present time it has concentrated its work on high school biology. Like PSSC and SMSG, BSCS has received federal grants from the National Science Foundation.

BSCS has directed its efforts toward producing a series of biology texts. A complete revision of the texts was completed in the summer of 1961. These revised editions had 110 contributors: 50 were college affiliated, 49 were from secondary schools, and the remaining 11 had various other affiliations.

Headquarters of BSCS is located on the campus of the University of Colorado. Dr. Bentley Glass is chairman of the study.

Organization and Structure

The organization and structure of BSCS biology differs from traditional biology courses in three major ways. First, BSCS attempts to present an outline of the total field of biology. Second, the course is organized around basic themes which provide a unified viewpoint of current biological knowledge. Third, BSCS seeks to give the student a concept of the centralness of scientific inquiry and investigation in biology.

In identifying the basic themes and structure of biology two factors guided the choices made by the biologists. Here, in their own words, is the explanation of these factors:

> First, we have examined the content and the structure of modern biology. From the content we have tried to identify those characteristics and conceptions which provide the most comprehensive and the most reliable knowledge of living things as they are known to modern biology. By examining the structure of enquiry in biology we have tried to identify the procedures and attitudes which best characterize modern biological science.
>
> Second, we have taken account of the needs and problems of students. We have asked ourselves what knowledge of living things, and what attitudes and skills relevant to biology, would contribute most to students' personal lives and to the execution of their responsibilities as men and citizens. Thus the second factor which has determined our themes has been the needs of our nation and our fellow citizens. By using both factors jointly, we have tried to fulfill our dual obligation: to reflect the current state of biology and to construct a defensible general education in biology at the high school level.[1]

Both of these factors were determined by the beliefs and opinions of the biologists. Students were not consulted about what they might feel to be important biological material which could contribute the most to their lives. The biologists made these decisions based on their knowledge of biology. The viewpoint is that of the biologists, not the students.

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[1] Biological Sciences Curriculum Study, High School Biology. Teacher's Handbook (All Text Versions), Part I. Revised edition. Boulder, Colorado: Johnson Publishing Co., 1961. p. 37.

Nine basic themes were identified by the biologists:

1. Change of living things through time--evolution
2. Diversity of type and unity of pattern in living things
3. The genetic continuity of life
4. The complementarity of organism and environment
5. The biological roots of behavior
6. The complementarity of structure and function
7. Regulation and homeostasis
8. Science as enquiry
9. The history of biological concepts.

These nine themes comprise one of the two elements which constitute the structure of the subject. For this reason each of these themes will be discussed briefly.

The first theme, evolution, is the most basic and pervasive of the nine. It provides a unity of viewpoint which is central to almost all biological thought. For one thing, it explains the history of all organisms. This history is concerned with an understanding of products, potentialities, means, and mechanisms of the process of evolution itself. This, in turn, directs attention to the possibility of controlling change among living things, such as has already been achieved by selective breeding and hybridization. Evolution also presents itself as a presently active, on-going phenomenon. This places emphasis on evolution as an active, dynamic force in everyday life processes.

Evolution is handled in three different manners in the course. Specific chapters of the text treat it as the history of living things. One chapter is devoted entirely to a discussion of the processes of evolution. Finally, evolution is closely related to all other phases of biology where it has relevance, especially where explanations of taxonomy, organic chemistry, and ecology are given.

The diversity of type and unity of pattern in living things, the second theme, actually represents another aspect of evolution. However, this theme is also handled at times separately from its relationship to evolution. This theme stresses the great diversity of living things. Yet, at the same time, the similarities that exist among and within these diversities are studied. Aspects of unity are taught by focusing attention on the universal roles of certain biological processes, for example, the behavior of ATP as the agent of energy exchange among organic matter. "There is similarly the universality of DNA and RNA as the materials of hereditary control, the common role of sugar as the fuel of life processes, the role of vitamins and coenzymes. At the cellular level, the unity of plan is seen in the remarkable unity of mitosis in cell division."[1]

As another aspect of evolution the second theme is treated in two manners. Specific chapters of the course deal with the unity and variety of living things. Likewise, the relationship of unity and diversity to the factors of mutation and natural selection is studied as part of the evolutionary process

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[1] Ibid., p. 41.

The genetic continuity of life is the third unifying theme of BSCS biology. This theme relates directly to theme number two, for the genes and their mutations account, in many cases, for both the unity and diversity of organisms. Thus, this theme is still another aspect of evolution.

Like all three themes so far discussed, number four, the complementarity of organism and environment, is a specific phase of the theme of evolution. Three aspects of this third theme are emphasized in the texts. The first is concerned with the influence of the environment on the whole organism. Next is the interaction of both organism and environment, each modifying and affecting the other. Last is the relationship, at every biological level--cellular, tissue, organ, system, and so on--between the appropriate "organism" and its environment. For example, the cells have their environment within a tissue, the tissue within an organ, the organ within the system, and the system within the total organism. Each level of biological organization can be studied in light of its own appropriate environment.

Theme five, the biological roots of behavior, includes the study of the limits and restrictions placed on living things by their biological natures. Taking space travel as an illustration, man must provide for his biological needs--oxygen, food, water, elimination, and so on--

if he is to survive. Man's capabilities are limited and controlled by the environmental conditions required by his organism.

The complementarity of structure and function, theme six, focuses on the close relationship between the structure of an organ and its function. Basic to this concept is the assumption that each biological structure functions in such a manner as to contribute to the wellbeing of the entire organism. Out of this assumption grows the assertion that the function of an organ can be derived from the study of its structure. The course enforces this theme in three ways. Whenever function or structure is discussed, it is related to the biology of the entire organism. In addition, a series of biological investigations in the "Invitations to Enquiry" is concerned with function and its supporting evidence. Also there is a section of the laboratory work devoted to the relationship between function and structure.

Closely related to the above is the next theme, regulation and homeostasis. This theme stresses the importance to an organism of a stable internal environment based upon the proper maintenance of certain levels of balance or equilibrium. The dynamic nature of behavior is taught as a means by which the organism regulates itself to change. Both text discussion and "Invitations to Enquiry" are used in handling this theme.

Science as enquiry, the eighth theme, is concerned with the materials and methods to be used in teaching BSCS biology. This theme represents a basic change from the approach used by most traditional biology texts. Instead of utilizing the standard rhetoric of conclusions found in most texts, the BSCS materials employ insofar as possible the natural methodology of science, scientific enquiry. Biology is taught as nearly as possible and practical as scientific investigation. There are times, of course, when the enquiry method is not used, but for the most part BSCS is taught as enquiry.

The final theme, the history of biological concepts, has two distinct elements. The first deals with the history of scientific investigation and enquiry. This is a related aspect of theme eight. The second element focuses on enquiry as a human enterprise. The role of chance and intuition as well as that of formal research method is accentuated. One purpose of the study of this theme is to give the students a clear and accurate conception of the nature of science and the role of the scientist.

Several generalizations can be made about these nine unifying themes. All nine are not concerned with the content of the course. Although themes one through five outline the contents of BSCS biology, the last two identify the approach to be used and the logical structure adopted. They focus on the nature of scientific knowledge and the roles of data and inference. Themes six and seven, on the other hand, are of an intermediate nature, having aspects of both content and methodology.

Knowledge of the nine unifying themes does not provide a complete picture of the structure of the subject. The second element of structure is the use of biological levels as an organizing factor for the nine themes. Seven levels of biological organization are identified by the biologists:

1. The molecular level
2. The cellular level
3. Organ and tissue
4. The organism as an individual
5. The population
6. The community
7. The world biome.

The unifying themes and the biological levels are carefully woven together to form the material of the course. The themes can be thought of as "horizontal threads woven through the entire material. The levels or areas of biology could be considered analogous to vertical threads. That is, the levels of biological organization and the BSCS themes can be considered the warp and woof of the texture of the BSCS materials."[1]

In preparing the texts for the course a decision was made to write three separate versions for the course. This was done for several reasons. "The life sciences are so diverse, both in point of view and in methodology, that there is no single best way to organize a high school course in biology."[2] Consideration was also given to the fact that by having several versions schools could choose the one which best seemed to serve their needs. Also the use of several versions provides a basis for determining whether or not a single version is best for all students. It may well be that a certain version will be most effective with students of similar ability. The use of multiple versions allows for effective comparison of the different versions.

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[1] Evelyn Klinckmann, "The BSCS Program for the Teaching of Biology." National Catholic Educational Association Bulletin 59:305; August 1962.

[2] Bentley Glass, "Renascent Biology: A Report on the AIBS Biological Sciences Curriculum Study." School Review 70:18; Spring 1962.

The extent to which the three versions differ is of major significance to this study. Since each version faithfully follows the thematic organization and presents material at each of the biological levels, there is no significant difference in the biological structure of each version. Differences are accounted for in terms of relative emphasis on different biological levels. The Blue version emphasizes the molecular; the Green, the community; and the Yellow, the cellular. A comparative examination of the three versions gives some idea of degree to which differences can exist within a course based on disciplinary structure.

In order to gain better insight into the differences among the three versions a list of the contents and a brief description of each of them is provided. Table 2 gives the contents of the Blue version.

An examination of Table 2 shows that the Blue version emphasizes evolution from the standpoint of physiology and biochemistry. The level focused on is the molecular, for the version attempts to outline the major contributions made by the study of molecular biology. The content gradually moves from simple to complex biological organization, beginning with the cell and concluding with the study of ecology.

The approach of the Green version differs considerably from that of the Blue, as is shown by Table 3. Ecology, physiology, and the

TABLE 2

TABLE OF CONTENTS OF THE BLUE VERSION OF THE BSCS

Section and Chapter	Title
Section I	Biology: The Interaction of Facts and Ideas
1	Scientists as Detectives
2	Varieties of Living Things
3	Evolution and Natural Selection
4	The Origin of Living Things
Section II	The Evolution of the Cell
5	The Emergence of Life
6	The Primitive Organism: Problems of Energy Utilization
7	The Primitive Organism: Problems of Duplication and Variation
8	The Primitive Organism: Food Makers and Respiration
9	The Modern Cell: The Evolved Heterotroph
Section III	The Multicellular Organism: New Problems of Life
10	Problems of Complexity
11	The Cell Theory
Section IV	The Multicellular Organism: Problems of Reproduction and Variation
12	Reproduction
13	Development
14	Patterns of Heredity
15	The Chromosome Theory of Heredity
16	Ways in which Genes Act
17	Genes in Populations
18	Genes and Evolution

TABLE 2--Continued

Section and Chapter	Title
Section V	The Multicellular Organism: Problems of Energy Utilization
19	Photosynthesis
20	Transport Systems in Plants
21	Transport Systems in Animals
22	Respiratory Systems
23	Digestive Systems
24	Excretory Systems
Section VI	The Multicellular Organism: Problems of Integration
25	Hormonal Regulation in Animals
26	Nervous Systems
27	Muscular and Skeletal Systems
28	Internal Regulation in Plants
29	Behavior and Adaptation
Section VII	Higher Levels of Organization
30	Populations
31	Societies
32	Communities

TABLE 3

TABLE OF CONTENTS OF THE GREEN VERSION OF THE BSCS

Section and Chapter	Title
Section I	The Biosphere Dissected
1	The World about Us
2	Individuals, Populations, and Communities
3	Animal Diversity
4	Plant Diversity
5	Microscopic Life
Section II	Patterns in the Biosphere
6	Life on Land
7	Life in Inland Waters
8	Life in the Seas
9	The History of Life
10	The Geography of Life
Section III	The Individual Dissected
11	The Cell
12	The Functioning Plant
13	The Functioning Animal
14	Reproduction and Development
15	Heredity
Section IV	Evolution, Behavior, and Man
16	Mechanics of Evolution
17	Behavior
18	The Human Animal
19	Man and the Biosphere

basic life processes provide the focus of the Green version. Beginning with the study of the biosphere this version ends with the study of man. In general, then, a deductive pattern is followed, since the version begins with the broadest biological level and moves eventually to the consideration of a specific organism. The specific content as well as the focus of the Green version differ widely from those of the Blue version. This is true in spite of the fact that both versions are based on the same structure.

The Yellow version has a still different approach to teaching the same structure of biology. Table 4 outlines the contents of the Yellow version. The focus of the Yellow version is on the cellular level of biological organization. However, other levels of biological organization are treated also. For instance, the last section deals with the ecological interrelationships of all organisms. Diversity is treated as a part of the study of microbes. Both plant and animal life are treated from the viewpoint of problems in the maintenance of life, the same basic approach as used in the Blue version. The section on development returns to the cellular level by emphasizing the factors involved in cell differentiation.

From the comparison of the content and approach of the three versions of BSCS biology two broad conclusions about the uniformity of curricula based on the same disciplinary structure can be drawn. First, it is apparent that a high degree of uniformity will be found among courses based on the same structure. The uniformity will, however, consist

TABLE 4

TABLE OF CONTENTS OF THE YELLOW VERSION OF THE BSCS

Section and Chapter	Title
Section A	Cells
1	The Study of Life
2	The Cell Theory
3	The Theory of Spontaneous Generation
4	Varieties of Cells
5	Tools for the Study of Cells: Chemistry and the Electron Microscope
6	The Physiology of Cells
7	The Reproduction of Cells
Section B	Microbes
8	The Kinds of Microbes
9	The Growth of Microbes
10	Microbes and Man
11	Microbes and Disease
Section C	Animal Life
12	Animals and Plants--An Introduction
13	The Animal Way of Life
14	The Diversity of Animals
15	Digestion in Multicellular Animals
16	Transportation and Respiration in Multicellular Animals
17	Excretion in Multicellular Animals
18	Coordination in Multicellular Animals
19	Animal Support and Locomotion
20	Reproduction in Animals

TABLE 4--Continued

Section and Chapter		Title
Section D		Plant Life
	21	Green Plants--Links between Two Worlds
	22	Photosynthesis--The Strategy
	23	Support and Conduction in Stems
	24	Roots--Anchorage, Absorption, and Conduction
	25	Movement and Storage of Materials within the Plants
	26	Reproduction in Plants
	27	Growth and Development in Plants
	28	The Diversity of Plants
	29	Man and the Balance of Nature
Section E		Development
	30	The Development of Animals
	31	The Analysis of Development
	32	Development in Plants
Section F		Genetics
	33	Patterns of Heredity
	34	The Chromosome Theory of Heredity
	35	Genes and How They Act
	36	Genes in Populations
Section G		Evolution
	37	Darwinian Evolution
	38	The Mechanism of Evolution
	39	The Origin and the History of Life
	40	The Evolution of Man
	41	The Cultural Evolution of Man

of the abstractions and generalizations that are being stressed rather than of specific content. Content may differ considerably from version to version, since the specific selection of items taught is based on the ability of such items to provide examples of the structure. Thus the diversity of animal life can be illustrated by an infinite number of species. Different biological levels of organization can also be used to show the mechanics of evolution. The influence of environment on evolution may just as easily focus on microbes as on man. Therefore, the same disciplinary structure can be taught by varying approaches and by means of different specific items of content. Also each of the approaches can accentuate, within structural limits, different aspects of the structure. Teaching structure does not eliminate differences among courses; it does not require that all teachers teach exactly the same material in the same way. Uniformity of structure does not necessarily result in uniformity of content. However, the broad abstractions and generalizations of the same discipline will possess a high degree of uniformity.

All three versions of BSCS biology were organized as separate subjects. Integration with other subjects of the curriculum was not attempted by any of the versions, although some effort is made to show the connection between biology and other sciences. The Teacher's Handbook,[1] a guide to all three versions, contains a section dealing with the relationships among biology, physics, and chemistry. Similar ties to other sciences are found in each of the text versions. There is some concern that BSCS biology is still too isolated from the other sciences. The director of BSCS states that one of the problems requiring additional study is the determination of the "proper interrelations of biology with other succeeding or preceding science courses at intermediate and secondary levels."[1] Continuing this line of thought, he further grants that more needs to be known "about the educational values of departmentalized successive courses (biology, chemistry, physics) versus an integrated science sequence of similar duration."[2]

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[1] Biological Sciences Curriculum Study, High School Biology. Teacher's Handbook (All Text Versions), Part II. Revised edition. Boulder, Colorado: Johnson Publishing Co., 1961. pp. 351-461.

No attempt has been made to relate biology to the nonscientific courses. Indeed, such possibilities have been entirely overlooked or ignored. BSCS biology undoubtedly has adopted the separate subjects curriculum for the present and for the immediate future.

Selection of Content

Much of what has already been discussed under the section on organization and structure is applicable to the selection of content. Knowledge of the nine unifying themes and the biological levels provides insight into the principles of selection. As with the other curriculum projects, the selection of content for BSCS biology is determined mainly according to its compatibility with the structure identified by the professional biologists. The process of selection consists of identifying the specific content which best illustrates or exemplifies the structure of biology, an activity largely left to the biologists.

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[1] Arnold B. Grobman, "The Revolution in Biology." Audio-visual Instruction 7:85; February 1962.

[2] Ibid.

In other aspects of content selection the BSCS procedure so closely parallels that of the other preposals that it is not necessary to repeat them here.

Sequence of Content

An examination of the contents of each version shows that the sequence is based on the familiar patterns of logical analysis and synthesis. The Blue and Green versions develop sequence by moving from the known to the unknown and from the general to the specific. The Yellow version moves from the simple to the complex. Sequence is developed according to the inductive and deductive patterns of logic.

Each of the versions follows the spiral curriculum characteristic of both PSSC and SMSG. Evolution serves as the basic idea developed by means of the spiral sequence.

BSCS material was developed to replace the traditional tenth-grade biology course.

Scope of Content

Biology, like mathematics and the other sciences, is experiencing an "explosion of knowledge." It has been estimated that every ten or fifteen years the amount of biological knowledge will double.[1] All future indications are that the rate of growth of significant biological information will continue to accelerate.

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[1] For elaboration of the impact of the explosion of knowledge on biology, see Bentley Glass, "Revolution in Biology." BSCS Newsletter 9:4-7; September 1961.

The scope of a biology course cannot be expected to cover all aspects of biology. Scope, then, was one of the major problems faced by BSCS as it set about to determine the material to be included in its versions. The solution to this problem was achieved by basing scope on structure. By patterning its scope upon disciplinary structure BSCS was able to limit the aspects of biology that had to be included in the course. Only those facets closely related to the nine unifying themes were included. In essence the criterion for scope, as for selection, is compatibility with structure.

Compatibility with structure is determined in two ways. First, the scope must be adequate to give the students a satisfactory understanding of the subject matter structure. In other words, the scope of the course must provide for the teaching of all aspects of structure. Second, scope must be adequate enough to provide ample illustrations of the concepts being taught.

Biological information not closely related to the nine themes is omitted from the course. As with the other curricula based on disciplinary structure, BSCS is characterized by a reduction in the breadth of topics taught. This is done so that greater depth of carefully selected topics can be achieved. Scope, in this case, becomes more a matter of vertical rather than horizontal expansion. In general the scope of BSCS biology is held strictly to the demands required to teach effectively the structure of modern biology.

Summary of the Three Projects

This brief examination of the three projects provides insight into the disciplinary structure approach to curriculum design. These insights are summarized below under the previously used curriculum design divisions: organization, selection, sequence, and scope.

1. In terms of curriculum organization, the three projects uniformly followed the separate subjects pattern. Each subject is taught as an individual course. Although there is some recognition of the interrelationships existing between each of the projects and other subjects, little effort is made to cross subject matter lines.

2. Content selection is left entirely to the scientists or scholars of the discipline. They alone determine what is to be taught. The selection of content is made by the subject-matter specialists as they identify the structure of the discipline. Using structure as the basis for content selection results in the teaching of the theoretical and abstract nature of the discipline. Application, technology, and similar aspects of the subjects are greatly curtailed in order that more time and effort may be devoted to the teaching of structure. Teaching structure results in emphasizing the intellectual nature of the discipline, a result clearly desired by the scientists and scholars.

3. The sequence of the content is determined by structure of the discipline. The logical unity of a discipline is contained within the structure. Therefore, in order to teach structure effectively, it is necessary to pattern sequence according to the logical relationships found within the subject matter. The spiral curriculum is used by all three projects to develop the logical unity of the structure. Various aspects of the structure are revisited at deeper levels as the course progresses. In planning the sequence the scholars and scientists seek the aid of teachers. The teachers are asked to translate the formal elements of the structure into the language and thought patterns of the learners. Sequence remains, however, the same as before, only the language is changed.

4. The scope of the three projects differs greatly from that of traditional courses. Each of the projects has limited its breadth in hopes of providing for more depth. There has, however, been some increase in breadth of scope. Each of the projects has up-dated its content to include topics not formerly studied. A corresponding reduction in scope has resulted from the elimination of most aspects of technology and application.

Scope, like the other aspects of curriculum design, has been adjusted to the requirements of teaching the structure of the subject matter.

5. The grade placement of the projects adheres closely to that of the traditional curriculum, biology being taught in the tenth grade, physics in grade twelve, algebra in grade nine, and geometry in grade ten. So far grade placement of specific subjects has been little affected by curricula based on disciplinary structure.

CHAPTER IV

EVALUATION OF THE EFFORTS TO IMPROVE THE SCHOOL CURRICULUM BY EMPHASIZING THE STRUCTURE OF THE DISCIPLINES

Chapter II of this study analyzed, described, and identified the bases of the curriculum design approach set forth by the Woods Hole Conference. This chapter will review the evaluative studies made of this approach to curriculum design. The evidence presented is based upon a review of the professional literature in education.

The presentation of the evidence is organized according to the five basic topics covered in the research. They are as follows:

1. Evaluation of student achievement
2. Reactions of students to the new proposals
3. Reactions of teachers to the new proposals
4. Reactions of parents to the new proposals
5. Reactions of subject-matter specialists to the new proposals.

The specific curriculum projects which are evaluated in this chapter are the School Mathematics Study Group (SMSG), the University of Illinois Committee on School Mathematics (UICSM), the University of Maryland Mathematics Project (UMMaP), the Physical Science Study Committee (PSSC), the Biological Sciences Curriculum Study (BSCS), the Chemical Bond Approach (CBA), and the Chemical Education Materials Study (CHEM Study).[1] Hereafter in this chapter these projects will be referred to by their initials rather than title.

Evaluation of Student Achievement

Most of the data used to evaluate the achievement of students studying SMSG mathematics were compiled by SMSG in evaluating its own program. In a study[2] undertaken by the Educational Testing Service (ETS) for SMSG in the fall of 1960 and spring of 1961, a comparison of student achievement in SMSG courses and traditional mathematics courses for grades seven, nine, ten, eleven, and twelve was made. Data were sought in relation to three questions.

The first question was, "Do students in SMSG courses master the traditional mathematical skills as well as students in non-SMSG courses?" To answer the first question a control group and an experimental group were organized. Teachers for both groups were selected at random. The control group was taught traditional mathematics; the experimental group was taught SMSG mathematics. Each of the two groups, experimental and control, consisted of approximately thirty sub-groups, each with its own teacher. These sub-groups were organized for five grade levels: seven, nine, ten, eleven, and twelve.

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[1] Evidence that each of these projects is based upon the disciplinary structure curriculum design approach may be found in Jerome S. Bruner, The Process of Education. Cambridge, Mass.: Harvard University Press, 1960, p. 2; or National Council of Teachers of Mathematics, The Revolution in School Mathematics. Washington, D. C.: The Council, 1961. pp. 16-27.

[2] Roland F. Payette, "Summary Report of the School Mathematics Study Group Curriculum Evaluation." SMSG Newsletter 10:5-11; November 1961.

Tests designed especially for the comparison of the two groups were constructed by ETS. A test of mathematical scholastic aptitude and knowledge was administered to the two groups in the fall of 1960. In the spring of 1961 a test of SMSG and traditional mathematics was administered to the two groups. The statistical analysis of the tests results indicates that there was no significant statistical difference between the two groups in terms of mastery of mathematical skills.

The second question was, "Do students in SMSG courses show a measurable increase in developed mathematical ability over that of students in non-SMSG courses?" Data to answer this question were secured by comparing the results of the control and experimental groups on tests designed specifically for SMSG courses. On the basis of these tests it was concluded "that students exposed to SMSG instruction acquire pronounced and consistent extensions of developed mathematical ability beyond that developed by students exposed to conventional mathematics instruction."[1] Thus students studying SMSG materials do better on SMSG tests than students who have not studied SMSG materials.

The third question was, "How well do students of different ability levels understand the material of SMSG?" Data on this question were derived by comparing SMSG test score distributions with the

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[1] Ibid., p. 10.

distribution of Scholastic Ability Test (SCAT) scores. Overlap for students of high, medium, and low scholastic ability as measured by SCAT and the SMSG test scores were determined. The results indicate that "there is positive evidence to suggest that students at all SCAT levels can learn considerable segments of SMSG materials."[1]

In a report[2] of several achievement studies conducted by the Minnesota National Laboratory, similar results were reported. The results of one study[3] based on the comparison of aptitude, as measured by the Differential Ability Test (DAT) for grades nine through twelve and the Scholastic Ability Test (SAT) for grades seven and eight, with achievement, as measured by the Sequential Tests of Educational Progress (STEP), indicate that SMSG students achieved as well as was indicated by their aptitude scores. The results for grades six and nine show that students in the lowest quartile did better than expected. Regardless of grade level high-ability students did well.

In a comparative study[4] of SMSG classes and traditional mathematics classes, no significant differences in mathematics achievement of the two groups were found, based upon a comparison of SAT and STEP test scores.

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[1] Ibid.

[2] Paul Rosenbloom, "Evaluation of SMSG, Grades 7-12." SMSG Newsletter 10:12-26; November 1961.

[3] Ibid., p. 13.

[4] Ibid., p. 14.

A study[1] of the effects of ability grouping on achievement in SMSG classes revealed that differences in grouping did not significantly affect the achievement of students of high mathematical ability; however, low ability students showed better achievement in classes without high-ability students than in classes heterogeneously grouped by ability.

In a summary of the above reports, it was concluded that "both studies show that students in SMSG classes do about as well as students in conventional classes on these tests."[2]

Later studies[3] of achievement by the SMSG evaluated the courses for grades four and five. Data for these evaluations are based on samples of 213 students in grade four and 194 students in grade five. Arithmetic aptitude scores were obtained from the administration of the Science Research Associates Arithmetic Achievement Test in the fall and the following spring. This test evaluates two arithmetical factors: reasoning and computation. The results indicate that the mean achievement of the SMSG groups was equal to or greater than the grade norms for both the fall and spring testing. In addition, the mean gain in achievement for reasoning and computation equaled or exceeded normally expected gains in relation to grade equivalents. This led to the general conclusion "that in terms of the test administered and its grade norms, the use of SMSG sample texts in grades 4 and 5 did not inhibit the mean arithmetic achievement of the pupils in the sample."[1]

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[1] Ibid.

[2] School Mathematics Study Group, "Introduction." SMSG Newsletter 10:3; November 1961.

[3] J. Fred Weaver, "Student Achievement in SMSG Classes, Grades 4 and 5." SMSG Newsletter 15:3-8; April 1963.

Another experimental study of SMSG courses compared the achievement of fourth-grade students taking the SMSG course to that of students taking a traditional mathematics course. The two groups were matched on the basis of IQ and arithmetic achievement. An attempt was also made to equate the teachers of the groups; however, the SMSG teachers appeared to have a slightly better mathematical background. Achievement was based on improvement on the Sequential Tests of Educational Progress Test 4a which was given in September, 1961, and the following May. The analysis of the data revealed "that there was no significant difference in the progress of the two groups . . . in traditional arithmetic over the school year."[2]

Shuff, in his doctoral thesis, made a comparison of the achievement of seventh- and eighth-grade students using SMSG and traditional mathematics materials. Basing his evaluation on the achievement scores of the two groups on the Sequential Tests of Educational Progress (STEP) and the Cooperative Mathematics Tests for Grades 7, 8, and 9 (COOP), Shuff found that his results lead "to the questioning of the claims of superiority of the SMSG text-materials. If the tests used in measuring the outcomes are considered valid for this purpose, the traditional materials must be accorded the more effective label. Some advantage for SMSG at the lower level [of ability] seemed to be indicated."[1]

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[1] Ibid., p. 5.

[2] Minnesota National Laboratory, "Evaluation of SMSG Text--Grade 4." SMSG Newsletter 15:10; April 1963.

In a similar study for grades nine and ten Williams found little difference between the two groups in grade nine. In grade ten the results were the same when achievement was measured by the COOP Intermediate Algebra test. "The group with SMSG mathematics training in grades eight and nine, however, tested significantly higher on the STEP. The selection of these students for participation in the grade eight SMSG program on the basis of performance in mathematics in grade seven might have accounted for this difference."[2]

Zant[3] states that preliminary comparisons of student proficiency in mathematics skills made by SMSG and the Minnesota National Laboratory reveal that students who had studied the SMSG courses and students who had studied conventional mathematics courses were about the same.

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[1] Robert V. Shuff, A Comparative Study of Achievement in Mathematics at the 7th and 8th Grade Levels under Two Approaches, School Mathematics Study Group and Traditional. Doctor's thesis. Minneapolis: University of Minnesota, 1962. 221 pp. Abstract: Dissertation Abstracts 23:559; No. 2, 1962.

[2] Emmet D. Williams, Comparative Study of SMSG and Traditional Mathematics. Doctor's thesis. Minneapolis: University of Minnesota, 1962. 193 pp. Abstract: Dissertation Abstracts 23:560; No. 2, 1962.

[3] James H. Zant, "Improving the Program in Mathematics in Oklahoma Schools." Mathematics Teacher 54:594-99; December 1961.

Wagner's[1] summary of the research reports the same results.

Achievement studies of the other mathematics projects cited by the Woods Hole Conference are not yet available with the exception of a single experimental study of the University of Illinois Committee on School Mathematics (UICSM) ninth-grade algebra course. This study compared the achievement, at low, middle, and high intelligence levels, of students studying a traditional ninth-grade algebra text and students studying the UICSM text. Based upon the comparison of standardized tests scores, the study revealed the following:

> 1. A statistically significant difference in the understanding of basic mathematical concepts in favor of the group using the contemporary [UICSM] program was obtained at the upper one-third intelligence level. No real difference was found between the two groups at either the middle or lower one-third intelligence level.
> 2. No apparent difference was found in the achievement of mathematical ability between the two groups at any level of intelligence.
> 3. No apparent difference was found in the achievement of manipulative skill between the two groups at any level of intelligence.[2]

No additional experimental data of student achievement in the mathematics projects were located.

Several experimental studies on student achievement in the science projects were found. The studies of student achievement in

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[1] John Wagner, "The Objectives and Activities of the School Mathematics Study Group." Mathematics Teacher 53:454-59; October 1960.

[2] M. LaVerne Loman, An Experimental Evaluation of Two Curriculum Designs for Teaching First-Year Algebra in a Ninth Grade Class. Doctor's thesis. Norman: University of Oklahoma, 1961. 54 pp. Abstract: Dissertation Abstracts 22:502; No. 2, 1961.

BSCS consist entirely of studies conducted by BSCS itself. However, these studies were planned and the test administered with the assistance of ETS.

Ferris reports that a comparison of scores made by BSCS students on the School and College Ability Test and tests designed especially for the BSCS course "are highly suggestive that the course materials are teachable to the average high school biology student."[1]

The first extensive evaluation of BSCS was undertaken during the 1961-1962 school year.[2] This evaluation of achievement was based on the results of three tests, two designed specifically for BSCS and one standardized test, the Cooperative Biology Test. The analysis of the test data prompted several conclusions relevant to this study. First the analysis of the data revealed that the BSCS students showed satisfactory progress. However, an analysis of the test data revealed that the materials were unsuitable for the lowest 20 per cent of the students who normally would be expected to take biology. Evidence also revealed that tenth-grade non-BSCS students scored significantly lower on the BSCS Comprehensive Examination than did the tenth-grade BSCS students. However, the non-BSCS students achieved significantly higher scores than the BSCS students on the Cooperative Biology Test. The difference between the two groups is partly explained by the fact that 25 to 40 per cent of the items on the Cooperative Biology Test are not covered in the BSCS texts.

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[1] Frederick L. Ferris, "Report on the 1960-61 BSCS Testing Program." BSCS Newsletter 10:5; November 1961.

[2] "Preliminary Report on 1961-62 Evaluation of New High School Biology Curriculum Materials Prepared by BSCS" (Biological Sciences Curriculum Study, University of Colorado, February 1963). 7 pp.

Another summary of the 1961-1962 BSCS evaluation reports that, although superior ninth-grade students taught by well-qualified teachers with ample laboratory facilities show satisfactory progress with BSCS materials, "BSCS Biology would probably not be suitable for the average ninth grader."[1] This summary also states that students who score high on the BSCS Comprehensive Final Examination usually also make high scores on both the BSCS Impact Test and the Cooperative Biology Test.

In general the evaluations made of the materials of the Physical Science Study Committee (PSSC) are similar to those of BSCS. In a study designed to compare the achievement of students who had taken a conventional physics course with that of PSSC students, the following results were reported:

> Thus students, taught physics using the traditional high school physics curriculum, performed significantly better on the Cooperative Physics Test than students taught high school physics using the curriculum developed by the Physical Science Study Committee; i.e., when scholastic aptitude, prior achievement in natural science physical science aptitude, and socio-economic status are statistically controlled and the variables of the teacher, physical plant, class time, and class size are held constant for both groups in the study.[2]

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[1] Biological Sciences Curriculum Study, "Summary of 1960-61 Evaluation Program Test Results." BSCS Newsletter 18:24; June 1963.

[2] Warren T. Kipsher, "Study of High School Physics Achievement." Science Teacher 28:37; October 1961.

The author of the report acknowledges that since the Cooperative Physics Test is a conventionally oriented test this might bias the results in favor of the conventional physics group. However, he also states that most colleges and universities are also oriented toward students with a traditional physics background. Thus there is some question about the effectiveness of the new curriculum as an adequate preparation for college physics.

Partly as a reaction to the above study, the PSSC reported some of its own findings on student achievement.[1] In 1957 the College Entrance Examination Board physics examination was administered to 300 PSSC students. The analysis of the data revealed that these students "did as well or better than others on those questions which dealt with topics covered in both types of courses, but that they did poorly on material with which they had no acquaintance prior to the examination."[2] As part of this same study students who had studied a conventional physics course were administered a test designed for the PSSC course. These students, in spite of the facts that they were older and had better science and mathematics backgrounds, scored significantly lower than did PSSC students. These results were interpreted as evidence that the evaluative instruments of one type of physics course are invalid measures when used with a different type of course. Thus, it was concluded that it is not valid to measure achievement in a PSSC course by a test designed for a conventional course. Neither is it valid to evaluate a conventional physics course by a PSSC test.

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[1] Physical Science Study Committee, "PSSC Versus Conventional Physics." Science Teacher 29:47, 49, 51, 53, 55; February 1962.

[2] Ibid., p. 55. See footnote 3.

The same article also summarizes a study of the college achievement of matched groups of PSSC students and students who had studied a conventional physics course. Based upon the types of grades received by the two groups in college, it was concluded that the "PSSC course does not penalize students who go to college."[1]

In a review of the 1958-1959 testing program of PSSC, Ferris reports that the evidence "overwhelmingly points to the conclusion that, not only is the course well within the capability of the great majority of U. S. high school physics students, but that experience in it is also highly profitable to a sizable percentage of relatively low-aptitude students. Further, the evidence refutes the prophecies of skeptics who surmised that the PSSC course would be appropriate only for the exceptionally 'bright' student."[2]

An aptitude study revealed that PSSC students' "mean composite verbal and quantitative score was approximately at the 95th percentile of the national norms group [for the School and College Ability Test of the Cooperative Test Series]. However, the range of scores extended well below the 75th percentile, the latter being the approximate lower limit for which the course was designed."[1]

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[1] Ibid., p. 53.

[2] Frederick L. Ferris, Jr., "An Achievement Test Report." Science Teacher 26:579; December 1959.

Another evaluation[2] of PSSC physics compared the achievement of PSSC students with that of students enrolled in conventional physics courses as measured by two types of achievement tests. One type was especially prepared for PSSC by the Educational Testing Service; the other type was constructed by the physics teachers themselves to measure pupil understanding of concepts and facts presented in the conventional physics course. The results of the testing program indicated that the PSSC course was not more difficult for students of comparable ability than the conventional physics course. In addition it was concluded that the PSSC students understood classical physics as well as students of comparable ability who had studied the conventional program.

Achievement data for the Chemical Bond Approach Project (CBA) are very limited.

Strong[3] reports that CBA developed a series of multiple-choice examinations to measure student achievement. The correlation of these scores with aptitude scores on tests administered by the Educational Testing Service suggests that many of the low-ability students are progressing considerably better than had been expected.

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[1] Frederick L. Ferris, Jr. "The Physical Science Study--Will It Succeed?" (Symposium) Harvard Educational Review 29:31; Winter 1959.

[2] Leon M. Lessinger, "An Evaluation of PSSC Physics." Journal of Secondary Education 37:97-99; February 1962.

[3] Laurence E. Strong, "Chemistry as a Science in the High School." School Review 70:44-50; Spring 1962.

These results are corroborated in a report on the CBA Project by Fraser:

> The results from examination data thus far show great similarity to those obtained in the PSSC physics program. Superior students, as judged by high scores on a scholastic aptitude test, were judged to have made excellent progress in the course, while a fair number of relatively poor students did "surprisingly well." In reporting these results, the CBA Project staff judged that, while more extensive data must be obtained, the new course appears to be within the reach of the typical high-school chemistry student.[1]

Evaluations of the Chemical Education Materials Study (CHEM Study) are also limited. Indeed, only two evaluations of the project are available in the literature. Campbell reports in a summary of the evidence "that the best students are more challenged, and the so-called poorer students more interested, than in the past. In fact, there is considerable evidence that an appreciable number of students with little indication of scientific ability in the past accomplish considerably more than would be expected of them in the CHEM Study course."[2] Based upon a comparison of achievement tests scores with performance on the Cooperative School and College Ability Tests, there was evidence that low-ability students did not have exceptional difficulty with the course. On the other hand, the same comparison indicates that a number of high-ability students had more difficulty with the course than had been expected.

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[1] Dorothy M. Fraser, Current Curriculum Studies in Academic Subjects. Washington, D. C.: National Education Association, 1962. pp. 13-14.

[2] J. Arthur Campbell, "Chemistry--An Experimental Science." School Review 70:53; Spring 1962.

These results are corroborated by a report by Merrill. He reports that, while the evidence is not conclusive, the results from the 1960-1961 testing program "suggest that students with comparable low scientific aptitude are achieving better in CHEM Study than they might have been expected to in a conventional course."[1] In addition, Merrill reports that the evidence indicates that the course challenges the superior students.

From this review of the research certain generalizations about student achievement in these new projects are apparent. First, students in the traditional courses score better on traditional tests than do students enrolled in the new projects. However, the differences between the two groups are often slight. On tests designed for the new projects, students who have studied the new projects consistently score higher than students who have studied traditional courses. With the exception of the two chemistry projects, low-ability students score lower on tests of the new projects than their ability would indicate. The opposite is true for the two chemistry projects. The achievement of average- and high-ability students in the new projects is about what would be expected. Thus, except for the low-ability students, the material of the new projects is appropriate for their respective student populations and grade levels.

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[1] Richard J. Merrill, "CHEM Study in Action." Journal of Secondary Education 37:73; February 1962.

Reactions of Students to the New Proposals

Student reactions are available for only two of the new projects. However, some additional evidence of student attitudes toward the projects is included under the section on teacher reactions, This additional evidence is classified under teacher reaction because it consists of teacher judgments of student attitudes about the projects. Only the reactions which the students themselves have made about the new projects are included in the present section.

In an attempt to measure student attitudes toward SMSG mathematics, an attitudinal inventory was devised by SMSG and administered in the fall and spring of the same school year to SMSG students in grades four and five. Based on a factor analysis of the students' responses it was concluded that these students did not develop negative attitudes toward arithmetic. Indeed, both sexes in both grades showed a slight increase in favorable attitudes toward mathematics.[1]

The results reported above are not substantiated by another study of student attitudes toward mathematics. A comparison was made of the changes in attitude of seventh-grade students who took the SMSG course and students who took a traditional mathematics course. Tests, questionnaires, and interviews were used to collect data. The analysis of the attitudes of the two groups toward mathematics in the fall of 1960 and the following spring revealed that the SMSG students had more favorable attitudes toward mathematics at the beginning of the school year than the non-SMSG students. "However, the data show that, at the end of the school year, the SMSG program has not been able to maintain momentum. While non-SMSG mathematics attitudes remained relatively constant, SMSG students' attitudes fell."[1]

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[1] J. Fred Weaver, "Student Achievement in SMSG Classes, Grades 4 and 5." SMSG Newsletter 15:7-8; April 1963.

During the 1957-1958 evaluation of PSSC it is reported that "not a single PSSC student requested transfer from the new course to other sections in which the conventional approach was taught, whereas the opposite was frequently true."[2]

In another evaluation of PSSC, "pupils stated that they experienced marked growth in their understanding of physics. They were particularly favorable towards their increased ability to see relationship, judge the usefulness of facts and the opportunity to experiment and use ideas."[3]

From such limited data it is difficult to draw a generalization. However, it appears that student reactions to the new programs are neither consistently favorable nor unfavorable, but appear to vary from time to time and from project to project.

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[1] R. Alpert, G. Stellwagon, and D. Becker, "Psychological Factors in Mathematics Education." SMSG Newsletter 15:23; April 1963.

[2] Ferris, Harvard Educational Review 29:31.

[3] Lessinger, Journal of Secondary Education 37:98.

Reactions of Teachers to the New Proposals

Perhaps the best source of teacher reactions to the new mathematics projects is found in a publication of the National Council of Teachers of Mathematics.[1] In addition to the SMSG, UICSM, and the UMMaP, this publication reports on the Ball State Teachers College Experimental Program, the Boston College Mathematics Series, the University of Illinois Arithmetic Project, and the Developmental Project in Secondary Mathematics of Southern Illinois University.[2] The reactions of thirty-five teachers,[3] all of whom have taught one or more of the new projects, are reported.

The teachers reported that they favored the new proposals even though many hours of additional work were required. They also reported that they did not wish to return to teaching conventional courses in mathematics.

Although these teachers stated that some students expressed a dislike for the new projects, they felt that a majority of the students reacted favorably to the projects. In general the teachers felt that the more capable students showed the greatest interest in the projects. Average students showed various degrees of interest, but most of them expressed a substantial amount of interest. The teachers reported that weak students reacted in much the same manner as they did to conventional mathematics courses.

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[1] National Council of Teachers of Mathematics, The Revolution in School Mathematics. Washington, D. C.: The Council, 1961.

[2] Evidence that these projects follow the curriculum design advocated by the Woods Hole Conference is found in National Council of Teachers of Mathematics, The Revolution in School Mathematics. Washington, D. C.: The Council, 1961. pp. 16-27.

[3] The report itself states, page 30, that there were thirty-three panelists; however, the actual list of the panelists, pages 89-90, includes thirty-five names, which is accepted as the correct number of panelists.

According to the teachers the majority of parents liked the new projects, although a few parents did react unfavorably. The more the parents knew about the projects the more they tended to approve of them.

In general the panelists felt that student achievement was better in the new programs. Several of the panelists offered evidence that students in the UICSM courses scored as well and often better on the College Entrance Examination Board tests than did students who had studied traditional mathematics. There was also a report that students who had had four years of UICSM mathematics were exempted from some college mathematics courses. In certain cases these students were permitted to take honors courses.

In general the panelists were highly in favor of the new projects.

Two teachers of SMSG mathematics have published articles praising the new program. One,[1] a teacher of seventh-grade mathematics, emphasizes the strength of SMSG in stimulating students to discover new ideas and concepts. The other teacher writes "that the students have a better overview of mathematics; they are aware of the fact that mathematics has a structure wherein all is related; nothing exists capriciously; everything is logically arrived at; one thing leads to another; patterns in mathematics can be discovered; mathematics can be exciting; and thinking mathematically can be fun."[1]

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[1] Humphrey C. Jackson, "Creative Thinking and Discovery." Arithmetic Teacher 8:107-11; March 1961.

In an evaluation of the SMSG program Zant[2] states that the teachers reported that students studying the SMSG program showed much more interest and understanding than did students enrolled in traditional mathematics courses. The teachers also felt that the SMSG students had shown outstanding growth in working word problems.

One teacher who has taught both the SMSG and UICSM materials stated that "the mathematical backgrounds of these students will be much stronger than it would have been if we had used traditional texts."[3]

Keedy[4] reports that teachers have shown much interest and enthusiasm for the UMMaP project.

The new mathematics projects, however, have not been uniformly well received by teachers. Manheimer[5] challenges the new programs on two grounds. He states that the new mathematics impairs understanding since it is descriptive rather than analytical. Thus students cannot use this information in the solution of other problems. His second point is that the new programs violate sound educational principles. Rather than moving from the concrete to the abstract, the emphasis is clearly on the abstract with little attention given to the concrete. Also Manheimer believes that these projects reverse the normal procedure of moving from the known to the unknown. Finally the complaint is made that the new projects overemphasize the need to rationalize all mathematical concepts. The danger here is that the explanation of the rationale is more difficult to understand than the application of the concept. Students are often not mature enough to understand the explanations offered. All of these shortcomings, according to Manheimer, reduce the effectiveness of the new mathematics programs.

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[1] Lillian Marlin, "SMSG--One Point of View." Mathematics Teacher 55:476-78; October 1962.

[2] Mathematics Teacher 54:597.

[3] Ross Taylor, "First Course in Algebra--UICSM and SMSG--A Comparison." Mathematics Teacher 55:481; October 1962.

[4] Mervin L. Keedy, "Mathematics in Junior High School." Educational Leadership 17:157-61; December 1959.

[5] Wallace Manheimer, "Some Heretical Thoughts from an Orthodox Teacher." Mathematics Teacher 53:22-26; January 1960.

In regard to teacher reaction to the PSSC course Finlay[1] reports that of 278 teachers who taught PSSC physics during the 1958-59 school year, 228 or 82 per cent elected to teach the course again. Of the 50 who did not teach the course again, 36 were in positions which made it impossible for them to teach the course. The remaining 14 teachers either decided not to teach PSSC physics or did not answer the inquiry sent to them.

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[1] Gilbert C. Finlay, "Summary of Judgments Made by Teachers." Science Teacher 26:579-81; December 1959.

In another study Ferris[1] reports that all eight of the teachers who had used PSSC materials during a 1957-1958 evaluation of the program stated that they would not wish to return to a traditional physics program. Lessinger[2] states that both teachers and administrators who have used PSSC materials reported that the course effectively taught physics and helped the students develop their rational powers.

In an evaluation of the CBA Project, Owen[3] reports that teachers using this approach were nearly unanimous in their praise for the program. These teachers felt that student interest and progress in the new program was excellent. They stated, however, that the slower students were having a difficult time with the CBA Project course.

Merrill[4] states that the teachers of the new CHEM Study course agree that both student interest and enthusiasm are high. In addition the teachers reported that they enjoyed teaching the CHEM Study course.

This review of teacher reactions to the new projects clearly suggests several generalizations. There can be little doubt that the teachers are overwhelmingly in favor of the new projects. They feel that student interest and achievement are higher than they were in the traditional program. However, there was a general feeling among the teachers that low-ability students reacted to the new projects in the same manner as they did to the traditional courses. The vast majority of the teachers report that they enjoy teaching the new projects much more than the conventional courses. The teachers also indicate that most parents approve of the new projects.

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[1] Harvard Educational Review 29:31.

[2] Journal of Secondary Education 37:98.

[3] J. Randall Owen, "Breakthrough in Chemistry Teaching." Overview 1:52-53; April 1960.

[4] Journal of Secondary Education 37:73.

Reactions of Parents to the New Proposals

Reports of the reactions of parents to the new proposals are severely limited. As was seen in the previous section on teacher reactions much of the information about the attitudes of parents is based on the interpretations and judgments of teachers. The teachers reported that the parents favored the new projects. Two statements of parental reactions to the new programs are reported in the literature. In his report, Keedy[1] states that parents expressed much interest and enthusiasm about UMMaP. Zant[2] also reports that parents are pleased with the new mathematics programs.

Thus teachers report that parents are generally pleased with the new projects.

Reactions of Subject-Matter Specialists to the New Proposals

The new projects were developed largely by the subject-matter specialists to provide for more effective subject matter presentation.[3]

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[1] Educational Leadership 17:157-61.

[2] Mathematics Teacher 54:597.

[3] Jerome S. Bruner, The Process of Education. Cambridge, Mass.: Harvard University Press, 1960. pp. 1-2.

This section will review the evidence on the reactions of the subject-matter specialists to the projects.

One source[1] cited earlier in this chapter reports that a three-man Consultant Panel,[2] composed of at least two subject-matter specialists, clearly reacted favorably to the new mathematics projects. In terms of subject-matter mastery the panel reported that "the evidence shows that the manipulative skill of pupils in the improved programs is at least as high as that of pupils in the traditional programs" and "the graduates of UICSM, the oldest of the improved programs, have done exceptionally well in college mathematics and science."[3]

Evidence that the subject-matter specialists favor the new projects is so pervasive in the literature that it would be impractical to attempt to review it here. Indeed, the review of the literature uncovered only one major criticism of the new projects by subject-matter specialists.

The major criticism, which deals with the mathematics projects, appeared in an article[4] signed by 75 professional mathematicians, almost all of whom are college professors. The criticism presented in this article centers around seven major aspects of the SMSG program.[1] The specific criticisms are given below:

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[1] National Council of Teachers of Mathematics, The Revolution in School Mathematics.

[2] Members of the panel were G. Baley Price, chairman of the Department of Mathematics, University of Kansas and, at this time, executive secretary of the Conference Board of the Mathematical Sciences; Kenneth E. Brown, specialist for mathematics at the Office of Education, U. S. Department of Health, Education, and Welfare; and W. Eugene Ferguson, head of the Mathematics Department, Newton High School, Newtonville, Massachusetts.

[3] National Council of Teachers of Mathematics, p. 23.

[4] Mathematics Teacher, "On the Mathematics Curriculum of the High School." Mathematics Teacher 55:191-95; March 1962.

1. Mathematics is not sufficiently related to its uses in science.

2. The logical structure identified is not necessarily the best means of teaching mathematics. Psychological order may sometimes be more effective.

3. Too much emphasis is placed on abstraction before providing students with sufficient background through concrete illustrations and applications.

4. Mathematical content is stressed at the expense of sound pedagogy.

5. The program does not provide for the needs of all students regardless of their ability and interests.

6. Too much emphasis is placed on formalized levels of rigor. Informal proofs and the like should also be presented.

7. The replacement of traditional aspects of mathematics should be undertaken only after they have been carefully scrutinized and found to be clearly outdated.

In a rebuttal Begle states that an examination of the SMSG texts will show that many of the same principles which were used in the criticism of the texts were "used by the SMSG writers, and that agreement with most of these guidelines is implicit in these texts."[2]

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[1] Although the article does not specifically name SMSG as the project being criticized, the fact that a rebuttal was written by E. G. Begle, director of SMSG, is evidence of its relevance to SMSG. Of course, the criticism is also applicable to most, if not all, of the other new mathematics projects. Begle's rebuttal is "Some Remarks on 'On the Mathematics Curriculum of the High School.'" Mathematics Teacher 55:195-96; March 1962.

[2] E. G. Begle, "Some Remarks on 'On the Mathematics Curriculum of the High School.'" Mathematics Teacher 55:195; March 1962.

No other major criticism of SMSG or the other mathematics projects was found in the review of the literature. It appears, then, that the majority of the mathematicians are satisfied with the new mathematics program. There are, of course, criticisms and disagreements over minor aspects of the projects, especially SMSG.[1]

Only one other criticism by a subject-matter specialist was located. This was a criticism of the PSSC physics program. One physicist complained that, since the new program was based on committee work, he feared that the individual and his role in physics was being too severely de-emphasized.[2]

In conclusion it appears that except for the mathematics projects the subject-matter specialists are almost unanimously in favor of the new projects. As to the mathematics projects there is some dissension among the specialists, but a clear majority of the mathematicians writing favor the new projects.

Summary

Evaluation of Student Achievement

1. Students in traditional courses score better on the traditional

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[1] See, for example, H. Van Engen, "A Note on 'Variable.'" Mathematics Teacher 54:172-73; March 1961; E. G. Begle, "Comments on a Note on 'Variable.'" Mathematics Teacher 54:173-74; March 1961; H. Van Engen, "On 'Variable'--A Rebuttal." Mathematics Teacher 54: 175-77; March 1961; Edwin Maise, "The New Mathematics Programs." School Review 70:82-101; Spring 1962; and Morris Kline, "The Ancients Versus the Moderns, A New Battle of the Books." Mathematics Teacher 51:418-27; October 1958.

[2] Reported in Arnold B. Arons, "The New High School Physics Course." Physics Today 13:20-25; June 1960.

standardized tests than do students enrolled in the new courses. The difference between the two groups is, however, slight.

2. On tests designed for the new courses students who have studied the new courses consistently score higher than students who have studied traditional courses.

3. In general low-ability students score lower on tests of the new courses than their ability would indicate. However, this was not true of students in CHEM Study or the CBA Project.

4. The achievement of average- and high-ability students studying the new courses is commensurate with their ability.

5. Except for low-ability students, the material of the new projects is appropriate for their respective student populations and grade levels.

Reactions of Students to the New Proposals

1. The evidence revealing student reactions to the proposals is very limited.

2. On the basis of available evidence, it appears that the student reactions are neither consistently favorable or unfavorable, but vary from time to time and from project to project.

Reactions of Teachers to the New Proposals

1. The teachers of the new projects are overwhelmingly in favor of the projects.

2. They report that student interest and achievement are higher than they were in the traditional courses.

3. The teachers report that low-ability students reacted to the new projects in the same manner as they did to the traditional courses.

4. The vast majority of the teachers report that they enjoy teaching the new projects and do not desire to return to the traditional courses.

5. The teachers also report that most parents approve of the new projects.

Reactions of Parents to the New Proposals

1. The evidence on parental reactions to the proposals is very limited.

2. On the basis of the available evidence, parents appear to be generally pleased with the new projects.

Reactions of Subject-Matter Specialists to the New Proposals

1. Except for the mathematics projects, the subject-matter specialists are virtually unanimously in favor of the new projects.

2. There is some dissension among the mathematicians about the new mathematics projects, but a clear majority of the mathematicians favor the new projects.

CHAPTER V

AN ANALYSIS OF LEARNING BY DISCOVERY

In recent years learning by discovery has become a topic of much discussion among educators. One reason for its present prominence in educational circles is its close connection with the disciplinary structure projects described in The Process of Education.[1] Sand and Miller consider learning by discovery to be one of the three major characteristics of these projects.[2] Bruner, himself, the reporter for the Woods Hole Conference, attributes his own interest in discovery to these projects:

> The immediate occasion for my concern with discovery . . . is the work of the various new curriculum projects that have grown up in America during the last six or seven years. For whether one speaks to mathematicians or physicists or historians, one encounters repeatedly an expression of faith in the powerful effects that come from permitting the student to put things together for himself, to be his own discoverer.[3]

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[1] Jerome S. Bruner, The Process of Education. Cambridge, Mass.: Harvard University Press, 1960. Taba holds this viewpoint. See Hilda Taba, "Learning by Discovery: Psychological and Educational Rationale." Elementary School Journal 63:308; March 1963.

[2] Ole Sand and Richard I. Miller, "Perspective on National Studies in the Disciplines." Journal of Secondary Education 38:29; January 1963.

[3] Jerome S. Bruner, "The Act of Discovery." Harvard Educational Review 31:22; Winter 1961.

The relationship of learning by discovery to the curriculum projects was identified by the members of the Woods Hole Conference. They recognized that the mastery of the structure of a subject required that the learner develop certain attitudes about the structure. The instilling of the proper attitudes was viewed as an area about which little is known, but it was felt that encouraging learning by discovery was a major aspect in creating the desired attitudes. The mathematicians and scientists both believed that it was possible and desirable to teach the structure of a subject in a manner that would reflect the excitement that occurs when a student makes a discovery on his own. Therefore, as the various projects were developed they included experiences in learning by discovery.

A second reason for present interest in learning by discovery stems from a new emphasis in research on the psychology of learning. Around 1955 research activity on learning by discovery began to increase rapidly. Prior to that time there was little research activity on this topic.[1] Most of the current interest in this phase of the psychology of learning is concerned with the effects of learning by discovery on transfer, retention, and concept development.

These two events have served to reinforce each other and greatly stimulate interest in learning by discovery. As is so often the case, this sudden growth has resulted in confusion. The purpose of this chapter is to make an analysis of learning by discovery in hopes of removing some of the confusion surrounding this term. The analysis will be sixfold:

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[1] Bert Y. Kersh, "Learning by Discovery: A Review of Recent Literature." Paper presented at the Symposium of the American Educational Research Association, Atlantic City, New Jersey, February 20, 1962. p. 1.

1. To describe the essential characteristics of learning by discovery and to derive a definition therefrom
2. To review briefly the rationale of learning by discovery
3. To identify and describe the advantages claimed for learning by discovery
4. To describe the purposes served by learning by discovery
5. To identify some of the new curriculum proposals which utilize learning by discovery
6. To identify the different methods of instruction for discovery.

Characteristics of Learning by Discovery

Bruner stresses the importance of recognizing that discovery is a learning process, "not a product discovered."[1] It is essential that this distinction between product and process be made; otherwise confusion will exist about the use of the term and the relationship between product and process will be overlooked. Since learning by discovery is a method of learning, it is fundamentally concerned with the experiences and behavior of the learner. From the study of these factors several educators have identified a single essential characteristic of learning by discovery which distinguishes it from all other types of learning.

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[1] Jerome S. Bruner, "On Learning Mathematics." Mathematics Teacher 53:612; December 1960.

This essential characteristic of learning by discovery is succintly stated by Ausubel:

> The essential feature of discovery learning is that the principle content of what is to be learned is not given but must be independently discovered by the learner before he can internalize it. . . . The learner must rearrange a given array of information, integrate it with existing cognitive structure, and reorganize or transform the integrated combination in such a way as to create a desired end product or discover a missing means-end relationship.[1]

Taba, in a recent article, practically paraphrases Ausubel's definition:

> The learner must construct his own conceptual schemata with which to process and to organize whatever information he receives. Teaching is directed to enable the learner to establish a relationship between his existing schemata and the new phenomena and to remake or extend the schemata to accommodate new facts and events.[2]

Bruner is in complete agreement with both Ausubel and Taba. He has stated that learning by discovery "is in its essence a matter of rearranging or transforming evidence in such a way that one is enabled to go beyond the evidence so reassembled to additional new insights."[3]

This essential characteristic of learning by discovery can be best understood by contrasting learning by discovery with expository or reception learning. According to Bruner, in reception learning "the decisions concerning the mode and pace and style of exposition are principally determined by the teacher as expositor; the student is the listener."[1] In discovery learning, however, Bruner continues to explain, the pupil is active. His behavior now helps set the mode, pace, and style of instruction. The pupil takes a part in the structuring of learning activities. He gathers evidence and tests hypotheses by manipulating data and questioning the teacher.

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[1] David P. Ausubel, "In Defense of Verbal Learning." Educational Theory 11:16; January 1961.

[2] Hilda Taba, "Learning by Discovery: Psychological and Educational Rationale." Elementary School Journal 63:308-16; March 1963.

[3] Harvard Educational Review 31:22.

Additional insight into the differences between reception and discovery learning is provided by Ausubel.[2] Discovery learning differs from reception learning in that while the former requires that the learner discover new ideas or content for himself, reception learning presents the learner with the ideas or content in a predetermined final form. There is no reorganization or manipulation of data. The learner is told the concept to be learned; he does not discover it for himself.

Included in the above descriptions of learning by discovery is the idea of the acquisition of new information. Learning by discovery if carried to completion makes something which was unknown known. The product of the process is a new understanding or an extension of what was known before, at least insofar as the learner is concerned.

This does not mean that the product must be something unknown to others. Bruner's caution not to "restrict discovery to the act of finding out something that before was unknown to mankind"[3] stresses the fact that the discovery itself may be new only to the learner. In the case of most school work this would certainly be true, the ideas to be discovered by the students already being known to the teachers. In this sense learning by discovery results in what is called concept attainment.

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[1] Ibid., p. 23.

[2] Ausubel, p. 16.

[3] Harvard Educational Review 31:22.

Concept attainment occurs when the learner himself first becomes aware, either through discovery or reception learning, of a concept which was already known to the person responsible for his instruction. Concept formation, on the other hand, is the discovery of ideas or concepts not previously known by either the learner or the instructor. Thus, concept formation is a highly creative act, far more so than concept attainment.

Learning by discovery may lead to either concept attainment or formation. However, all studies of learning by discovery known to the author have so far been limited to concept attainment. At present little is known about fostering concept formation, so little, in fact, that the area is just beginning to be explored.[1] The new curriculum projects mentioned by the Woods Hole Conference, for instance, use learning by discovery to foster concept attainment. In these cases the concepts to be attained are aspects of the disciplinary structure that have been identified by the scientists or scholars.

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[1] J. Richard Suchman, The Elementary School Training Program in Scientific Inquiry. Title VII Project Number 216, National Defense Education Act of 1958. Grant No. 7-11-038. Urbana, Ill.: University of Illinois, 1962, p. 19. See also Jerome S. Bruner, Jacqueline J. Goodnow, and George A. Austin, A Study of Thinking. New York: John Wiley and Sons, 1956, p. 232. It is also worthy of note that at least one study of what would now be clearly considered concept attainment employs the term concept formation in its title: Finley Carpenter, "The Effect of Different Learning Methods on Concept Formation." Science Education 40:282-85; October 1956.

Other characteristics of learning by discovery have also been identified, but these are either shared by other learning processes or are limited to one or two of the various forms of learning by discovery. Taba,[1] for example, states that learning by discovery is characterized by inductive processes. Reception learning may also proceed through inductive processes.[2]

Another important but not unique characteristic of learning by discovery is the fact that it begins or is initiated by a problem situation. In this sense, learning by discovery is a type of problem solving. Indeed, Taba[3] traces the history of modern learning by discovery through Dewey's work on inquiry and problem solving.

Attention is called to the fact that only one of the three major characteristics of learning by discovery identified above is an essential element: the independent reorganization or extension by the learner of his own cognitive structure. From this essential characteristic it is now possible to derive a working definition of learning by discovery. Thus, learning by discovery may be defined as the process of the independent reordering or extension of cognitive structure by the learner which culminates in the learner's acquisition of one or more new concepts.

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[1] Taba, p. 312.

[2] It might also be added that it is the present writer's opinion that learning by discovery may occur through deductive as well as inductive processes. Geometry and logic, in particular the syllogism, are areas where discovery by deduction might easily occur. Support for the author's view is found in Gertrude Hendrix, "Learning by Discovery," Mathematics Teacher 54:298; May 1961, and M. T. Keedy, "Mathematics in Junior High School." Educational Leadership 17:159; December 1959.

[3] Taba, pp. 308-10.

The Rationale of Learning by Discovery

There has not yet appeared a definitive study of the rationale of learning by discovery. In order to develop an understanding of this rationale it is necessary to draw upon many separate sources and to attempt to synthesize the various points of view into a coherent framework. Only one detailed explanation of discovery rationale was located. Even in this case, the treatment is confined to only one specific approach to discovery learning, the Illinois Studies of Inquiry Training. Since so little has been written on the rationale of discovery learning, this section will present the rationale of inquiry training.

Illinois Studies of Inquiry Training

The purpose of the Illinois Studies of Inquiry Training "has been to help children develop a set of skills and a broad schema for the investigation of causal relationship."[1] The desired outcome of such training is to enable the learner to achieve greater independence and autonomy in concept development.

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[1] Suchman, p. 3.

Two assumptions rest behind the rationale of inquiry training. First, it is assumed that there is a high degree of uniformity among the fundamental thought processes used in inquiry and that these fundamental processes are the same for all disciplines. A second assumption is that the rate of intellectual growth, as identified by Jean Piaget and Bärbel Inhelder,[1] can be accelerated by teaching children the fundamental processes of inquiry.

According to Suchman the rationale of inquiry training consists of three tenets:

1. Inquiry training frees the learner to formulate new ideas and relationships according to his individual ability and his own cognitive needs; thus, it promotes autonomy of learning.

2. Motivation is intrinsic within inquiry, for children enjoy self-directive activity that results in intellectual growth.

3. Concepts achieved through inquiry are more meaningful to the learner because they result from his own needs, behavior, and motivation.

The structure and function of inquiry.--Four aspects of inquiry behavior have been isolated and studied by the Illinois Studies of Inquiry Training: searching, data processing, discovery, and verification. A description of each of these four aspects follows.

Searching is characterized by behavior designed to gather data according to a systematic plan. It is a selective process which allows the inquirer to adjust his data assimilation to the requirements of his purpose. Two aspects of searching account for much of its value as a device for the collection of data. The first of these is mobility. This permits the inquirer to capitalize on a wide range of data sources. Manipulation is the second aspect. Through manipulation the inquirer can subject the environment to selected changes to observe the effects and determine their relevance to the task. New data are often produced by this means. Whereas mobility provides new sources of data, manipulation increases the amount of data obtainable from a single source.

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[1] A brief description of the Piaget-Inhelder viewpoint is found in Chapter II of this study. A full treatment is given in Bärbel Inhelder and Jean Piaget, The Growth of Logical Thinking from Childhood to Adolescence. New York: Basic Books, Inc., 1958.

The searching behavior of inquiry has four basic characteristics. First, there must be a locus in which to search. Second, there must be freedom to explore the locus. Third, there must be a "set" to direct the searching activity. Finally, there must be a plan to follow in carrying out the search. Of these four characteristics that of set is of special importance. Sets direct the searching activity into certain areas while closing off other areas. Sets permit the inquirer to focus his efforts along selected lines without having to attend to all possible data sources. The problem is to retain enough richness and variety of sets as are possible without interfering with a systematic approach in the search for data. This is a variation on the theme of freedom within limits. The limits must give order to the search without severely limiting the variety of data sources available.

Data processing serves to organize the results of the search into patterns that reveal regularities in the data. Briefly it is the means of developing relationships among the data collected. The processing of data falls into four divisions:

1. Analysis--subdivision of data into their parts.

2. Comparison--identification of similarities and differences of the data.

3. Isolation--selectivity of variables for intensive examination.

4. Repetition--continuous presentations of data to increase opportunities for selection as subjects of investigation.

Discovery is achieved when the data processing is culminated by a synthesis leading to an explanation or understanding of the inquirer's problem. Specifically discovery occurs when previously noted conflicts, dissonance, or discrepancies are resolved by additional insight. There are at least two ways in which solution can occur. A synthesis may be developed from data that originally appeared to be incompatible. Sometimes the divergent data fall into patterns that match other concepts previously learned. Discovery may also result from a conceptual shift, the development of a new concept which fits the data. However, inquiry training does not attempt to teach the learner to develop or invent new conceptual schemes. This is considered beyond the intent of the program.

Verification is the process of checking the discovery against reality to ascertain its soundness. Most often this is accomplished by testing the concept against specific instances to see how well it allows prediction.

Inquiry training.--The training program begins with the presentation of a short motion picture which establishes a problem situation. The learners are encouraged to seek the solution to the problem posed. This they may do by questioning the teacher about the motion picture. They may not, however, ask for generalizations or explanations. By this process of inquiry an analysis is made of the presentation and hypotheses are offered as explanations of the phenomena observed. This process consists of two phases: "(a) interpreting data in terms of pre-existing concepts and (b) modifying concepts to correspond to the data. . . ."[1] These two phases are known as assimilation and accommodation, respectively. One of the major purposes of inquiry training is to help children learn to carry out these two phases more autonomously and efficiently.

Assimilation and accommodation are mutually dependent upon each other in promoting conceptual growth. The learner must effectively use first one and then the other. He must assimilate new data and, at the appropriate time, accommodate previously existing cognitive structure to these data. Once the cognitive structure has been modified to incorporate the new data, the learner again sets out to assimilate additional data. This process continues until the explanation is discovered.

Inquiry training attempts to make discovery more efficient by providing the learner with a better strategy for seeking solutions to problems. In other words, it attempts to teach the learner a strategy for inquiry. There are four key elements involved in setting up a program for inquiry training. The first of these is the problem episode. The purpose of this episode is to present the learner with a problem on which to work. The short physics films spoken of earlier are used for this purpose. These films serve as stimuli for inquiry.

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[1] Suchman, p. 23.

The second element, the responsive environment, provides the sources of data needed to discover the explanation for what was observed in the film. No attempt is made to structure the form or sequence of the data. The learner determines both of these by the questions he asks. There are, however, certain limitations imposed on the questioning. All questions, for instance, must be phrased so that they can be answered by either "yes" or "no." Other questions must be recast until they fit this pattern.

The third element changes the focus of the inquiry from content to process. This change is accomplished (1) by providing opportunities for directed inquiry practice, (2) by developing the plan for analyzing causality, and (3) by mastering a method for investigating causal relations.

Practice in more efficient inquiry is developed mainly through two methods. First, the teacher helps the learner realize why he runs into trouble when following inappropriate lines of inquiry. Second, tape recordings are made of inquiry sessions and later criticized to point out weaknesses and strengths. From this the learners are able to ask better and more germane questions.

Teachers help the learners to analyze causality by seeking information about the following five facets of the problem episodes:

1. The objects contained in the episodes

2. The systems, interrelated assemblies of objects, presented by the episodes

3. The conditions existing, especially those which change, during the episodes

4. The events which occur during the episodes

5. The properties of the objects identified in the episodes.

The learners are assisted in identifying and describing these five facets and in noting the relationships that exist among them.

The last aspect of focusing inquiry on process entails the learning of a schemata for inquiry. Although there are various approaches to strategies of inquiry, the Inquiry Training Program has settled on three phases: episode analysis, the determination of relevance, and the induction of relational constructs.

Episode analysis consists of routine checks made on the objects and systems identified in the problem episode. This is done in order to determine the properties of the objects and systems. The learner may do this by asking the teacher if an object is a certain thing or has specific characteristics. Another method is to ask if a certain thing would happen if the object were subjected to specific conditions. In addition the analysis includes determining the state of the objects and systems at the episode's beginning and at the completion of each successive distinct event. The last aspect of the analysis consists of having the learners present their data in organized chart form. A standard form for this chart has been developed by the Inquiry Training Program. Its purpose is to aid the learner in recognizing patterns and relationships among the data.

The determination of relevance characteristically involves two goals. The first is to establish the relevant variables of the episode and the conditions necessary for their operation. This goal is achieved by changing one variable at a time while holding the others constant. The second is to identify the conditions relevant to the results of the episode. Questions are used to gather the information needed to satisfy both goals.

Phase three, the induction of relational constructs, is designed to help determine why certain conditions must be present for the results to occur as observed. Unfortunately, attempts to identify a standardized procedure for this phase have failed. Previous experience, intuition, and creativity all seem to influence the effectiveness of the learner's behavior. "Here is where the individual brings to bear his existing conceptual systems in hypothesizing causal relationships and testing them."[1]

An example of a typical session of Inquiry Training is given in Appendix I. Much of the rationale described above is easily identifiable in this example.

Up to this point the rationale presented has been limited to a single approach to learning by discovery, inquiry training. Now attention is focused on the general rationale of all approaches to learning by discovery, including inquiry training. As mentioned earlier this rationale is derived from a synthesis of many separate sources on learning by discovery.

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[1] Ibid., p. 42.

General Rationale of Learning by Discovery

The basic tenet of learning by discovery challenges the assumption that the process of learning can best be controlled by some person other than the learner himself. Expository learning, according to Suchman, provides no place "for search, for data gathering and processing or for discovery. The learner is reduced to the level of the machine itself, and only the most menial of human cognitive functions are called into play. The creative and divergent aspects of human intelligence are for the most part ignored and neglected."[1] It is largely to overcome these drawbacks that learning by discovery has been advanced as an improved technique for promoting learning. The first assumption of learning by discovery, then, is that the learner himself is best able to direct his own learning and that learning by discovery is the most effective means yet developed to foster the learner's self-direction.

A second tenet of learning by discovery is that it provides a concrete basis for the development of abstract ideas. This tenet is based upon the research of Bärbel Inhelder and Jean Piaget. Their research indicates that, prior to the upper elementary grades or junior high school, learning should be based more upon concrete activities, such as those afforded by discovery and other largely nonverbal experiences, rather than upon more formalized and highly verbal activities.[1] Thus developmental considerations have influence on the interest in learning by discovery. Adding to this line of reasoning Ausubel states:

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[1] J. Richard Suchman, "Making Room for Searching Minds: Prospects for Education through Inquiry." Paper presented at the Leadership Conference sponsored by the California State Department of Education, Asilomar, California, August 8-12, 1961. p. 4.

> Furthermore, for children who are still functioning at Piaget's level of concrete operations, nonverbal, intuitive discovery and application of principles, prior to formal verbalization, is often desirable, in addition to the use of concrete-empirical props. In learning more complex and abstract ideas far removed from everyday experience, it is plausible to suppose that subverbal insight acquired through discovery experience may serve as a facilitating transitional phase in the achievement of full verbal understanding.[2]

Ausubel's comments on subverbal insight lead to a third tenet of the rationale of learning by discovery. This tenet holds that subverbal understanding precedes the ability to verbalize what is understood. Thus, the discovery is made and understood before it can be expressed verbally. "The separation of discovery phenomena from the process of composing sentences which express those discoveries is the big new breakthrough in pedagogical theory."[3] Discovery of the generalization occurs before the learner is able to verbalize what he has found. In discovery learning subverbal insight later emerges as verbal statements. In reception learning the approach used is different. The learner is presented with a verbal generalization and expected to gain insight from it. The proponents of learning by discovery claim that providing a verbal generalization leads to rote learning because the learner can only memorize a generalization that he does not really understand. If, on the other hand, the learner had discovered the generalization for himself, he would have first gained subverbal insight and later verbalized his own understanding of the generalization. Such a process insures that the understanding and the verbalization are as nearly the same as possible.

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[1] Bärbel Inhelder and Jean Piaget, The Growth of Logical Thinking from Childhood to Adolescence. New York: Basic Books, 1958.

[2] David P. Ausubel, "Learning by Discovery: Rationale and Mystique." National Association of Secondary-School Principals Bulletin 45:18-58; December 1961.

[3] Gertrude Hendrix, "Learning by Discovery." Mathematics Teacher 54:290; May 1961.

Whereas the expository or reception techniques of teaching tended to divide learning into two aspects, content assimilation and the process for organizing and using the content, the "rationale of learning by discovery seems to bring process and content into a transactional relationship. The rationale stresses the need for a strategy for cultivating autonomous mental processes in relation to the requirements of the structure or the logic of the particular content."[1]

The transactional relationship between the content and the process is an outgrowth of the learner's need to process new content so that it is assimilated to his own conceptual schemata. In certain cases where the new content cannot be readily assimilated to the previous cognitive schemata, the schemata is reorganized so as to facilitate the new content. Thus each of these two aspects of learning transacts with the other. In fact, the content is learned as the result of a process, learning by discovery, which reveals the relationship between content and cognitive schemata. Stressing this important quality of discovery, Taba explains:

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[1] Taba, p. 311.

> The act of discovery occurs at the point in the learner's efforts at which he grasps the organizing principle imbedded in a concrete instance or in a series of instances and can therefore transform this information: the learner can see the relationship of the facts before him, he can understand the causes of the phenomenon, and he can relate what he sees to his prior knowledge.[1]

Taba also stresses the connection between discovery and the structure of the subject matter being studied. The discovery should reflect the logic or structure of the subject matter. This completes the transactional relationship between content and process, for the content itself has structure.

Strategies of Learning by Discovery

Taba also reports that all types of learning by discovery have a specific teaching strategy. Three aspects of strategy appear to be common to most types of learning by discovery. The first of these is the presentation of a problem situation which is designed to initiate the process of learning by discovery. A second aspect is the withholding of principles and generalizations in order to lead the learner into the discovery of these principles or generalizations on his own. The third aspect of strategy is the freedom given to the learner to direct his own actions in seeking and reorganizing data so that he may formulate additional insights for himself. Other aspects of strategy are found in specific types of learning by discovery, but the three given here are common to virtually all types.

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[1] Ibid.

Advantages Claimed for Learning by Discovery

The proponents of learning by discovery claim that there are several important advantages of this method of teaching. The most significant of these are (1) it strengthens and extends intellectual potency and cognitive skills, (2) it is intrinsically rewarding, (3) it teaches the heuristics of discovery, (4) it aids memory processes, (5) it makes learning more meaningful, and (6) it promotes transfer of learning.[1]

Bruner believes that intellectual potency and cognitive skills are improved by learning by discovery, for learning by discovery helps students develop effective means of problem solving. Three such means, strategies, are suggested. First, the student can be aided in learning to ask questions which locate constraints in the problem. Constraints serve to progressively eliminate wide ranges of possibilities and aid in the reduction of hypotheses to be explored. For example, the student who asks, "Was the error the result of inaccurate computation?" is working, by locating constraints, more efficiently than the students who ask, "Did the error result from incorrect division?" The second student might be fortunate in immediately finding the solution, but if he were wrong, the error could still result from inaccurate multiplication, addition, or subtraction. The first student, if he received a negative reply, could immediately explore other areas.

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[1] Bruner, Harvard Educational Review 31:26-32. J. Richard Suchman, "Inquiry Training: Building Skills for Autonomous Discovery." Merrill-Palmer Quarterly 7:147-51; July 1961.

A second means of improvement is to teach students to ask questions which fully utilize previous information. By locating constraints in the problem the student can then use his knowledge of the constraint to help him formulate his next questions. In other words, each successive question builds upon the information gathered by previous questions.

The third element is persistence which, in turn, consists of two facets: sheer perseverance and an organized means of collecting and storing information. The student who has organized his search for information and its storage is able to succeed where a student who has followed an unorganized pattern of search and storage becomes confused and discouraged. Bruner labels the strategy of the first student cumulative constructionism; that of the second, episodic empiricism. Thus, he asserts that the intellectual potency of students is improved by having them utilize the strategy of cumulative constructionism. Practice in discovery leads the student to search for more effective methods of gathering and storing information.

The second advantage of learning by discovery, intrinsic motivation, is based upon the concept of competence as a motivating factor.[1] This concept holds that the child has an intrinsic need to explore and manipulate his environment. He will of his own accord seek to discover things around him without being guided by extrinsic rewards.

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[1] See Robert W. White, "Motivation Reconsidered: The Concept of Competence." Psychological Review 64:297-333; September 1959, for a first-hand discussion of this concept.

Bruner believes that learning by discovery capitalized on this intrinsic motivation by allowing the learner to guide or direct his own behavior. As the learner discovers new ideas and facts about his environment he gratifies his need for greater competency. Thus learning by discovery is said to have intrinsic motivation.

Relying upon the intrinsic motivation of learning by discovery also helps to curtail the negative influences of extrinsic controls often used by both parents and teacher. "That is to say, learning that starts in response to rewards of parental or teacher approval or the avoidance of failure can too readily develop a pattern in which the child is seeking cues as to how to conform to what is expected of him."[1]

Teaching the heuristics of discovery can, according to Bruner, be accomplished only by utilizing problem solving or discovery methods. Practice in learning by discovery leads the learner to develop a style of work from which he can formulate principles to guide future attempts at discovery. If the principles are to be truly generalities that can be used in a wide variety of situations, then it is necessary for the learner to undergo extensive practice with many types of problem situations. At present very little is known about the methods of instruction which most effectively teach heuristics of discovery. Indeed, Bruner has no suggestions to make here. He merely affirms that heuristics of discovery can be taught only by engaging in discovery itself.

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[1] Bruner, Harvard Educational Review 31:26.

Practically all authorities who favor learning by discovery cite its influence in aiding memory as one of its advantages, especially Suchman,[1] Taba,[2] as well as Bruner, who explains that "the very attitudes and activities that characterize 'figuring out' or 'discovering' things for oneself also seem to have the effect of making material more readily accessible in memory."[3] These authorities agree that the processes by which the learner discovers the principles being sought are, in and of themselves, of such a nature that improved memory of the discovered principle occurs as a natural by-product.

Only Bruner explains how learning by discovery brings about the improvement in memory. Basing his conception of memory on the work of George A. Miller,[4] Bruner states that the problem of memory is one of retrieval, not storage. The problem, then, becomes one of how best to commit the information to memory so that it may easily and accurately be recalled to consciousness. This may be achieved by organizing the information in such a manner that it is integrated into the learner's cognitive structure. Learning by discovery does just this, for it permits the learner to direct his own learning according to his own interests and cognitive structure. Thus newly acquired ideas and facts are organized by the learner so as to be effectively related to previously existing ideas and facts. Since the new information is related to previously existing cognitive structure which can be readily remembered, the new information itself can be recalled upon demand.

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[1] Merrill-Palmer Quarterly 7:147-69.

[2] Taba, pp. 308-16.

[3] Harvard Educational Review 31:32.

[4] George A. Miller, "The Magic Number Seven, Plus or Minus Two." Psychological Review 63:81-97; March 1956.

The fifth advantage, that of making learning more meaningful, is probably the widest proclaimed benefit of learning by discovery.[1] Central to this claim is what is meant by "meaningful." Taba recognizes this problem and offers the following explanation:

> The essence of meaningfulness seems to be centered in the penetration into the basic structure of whatever one deals with, the mastery of the regularities and principles that govern the relationships of the phenomena observed, and the ability to use this knowledge in explaining a wide range of phenomena.[2]

Much the same idea of meaningfulness is contained in an explanation that Kersh offers to explain why learning by discovery enhances meaning:

> Through the discovery process, in which the learner is forced to rely on his own cognitive capacities, he becomes cognizant of the relationships of the learning task to his previous experience, or to the pattern of relationships among the elements of the task.[3]

Suchman states that learning by discovery is more meaningful because it is intrinsically rewarding, builds the learner's self-confidence in his own abilities, improves cognitive skills, and teaches the learner to detect pattern and organization in data.[4]

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[1] Taba, pp. 308-16.

[2] Ibid.

[3] Bert Y. Kersh, "The Adequacy of 'Meaning' as an Explanation for the Superiority of Learning by Independent Discovery." Journal of Educational Psychology 49:282; October 1958.

[4] Merrill-Palmer Quarterly 7:148.

Each of these explanations stresses that meaning is derived from the learner's awareness of the relationships between the principle discovered and his previous cognitive structure. Awareness of these relationships imbues the discovery with meaning.

Improvement in the transfer of learning, the last advantage claimed for learning by discovery, was hypothesized by Hendrix in 1947: "For generation of transfer power, the unverbalized awareness [discovery] method of learning a generalization is better than a method in which an authoritative statement of the generalization comes first."[1] In the same article Hendrix states that the key to transfer is not the ability to verbalize the principle discovered. Indeed, she offers evidence that verbalization of the principle reduces the power of the subjects to transfer the principle to later situations. The key to transfer of learning, she states, "is a sub-verbal, internal process--something which must happen to the organism before it has any new knowledge to verbalize."[2] In a more recent article Hendrix[3] reaffirms her belief that the nonverbal awareness of principles promotes transfer. Nonverbal awareness of principles is, of course, attained by discovery learning; therefore, learning by discovery is credited with improving transfer power.

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[1] Gertrude Hendrix, "A New Clue to Transfer of Training." Elementary School Journal 48:198; December 1947.

[2] Ibid., p. 200.

[3] Mathematics Teacher 54:292.

Purposes Served by Learning by Discovery

Three distinct purposes of learning by discovery can be identified in the literature dealing with this topic. These three purposes are (1) to teach subject-matter content, (2) to teach the heuristics of discovery and inquiry, and (3) to teach the nature of the knowledge discovered. In addition to these three distinct purposes, learning by discovery can also be used to serve a combination of any two or all three of these purposes. Taba recognized the unity of content and process, numbers one and two above, when she wrote that the rationale of learning by discovery "stresses the need for a strategy for cultivating autonomous mental processes in relation to the requirements of the structure or the logic of the particular content."[1] Bruner emphasizes the relationship among all three purposes. He believes that the "process and the goal of education are one and the same thing. The goal of education is disciplined understanding. That is the process as well."[2] In the same article Bruner developes the relationships that exist among subject matter, the nature of knowledge, and learning by discovery.

As was indicated earlier, however, learning by discovery can be limited to only one or two of these purposes. In fact much of the work on discovery has concerned itself with one of these purposes. Appendix J contains a list of ten sources which are limited to problems and procedures for teaching subject matter effectively. All ten are experimental studies designed to test the effectiveness of teaching subject matter by discovery. The content to be discovered is drawn from such various subjects as physics, mathematics, and English. Three of the studies are concerned with teaching skills.

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[1] Taba, p. 311.

[2] "After John Dewey, What?" Saturday Review 44:77; June 17, 1961.

Sources on using learning by discovery to teach the heuristics of discovery and inquiry are given in Appendix K. Of the thirteen sources contained in this appendix, six are experimental, five are expository, and two are combinations of both exposition and experimentation. The rationale behind teaching the heuristics of discovery has already been treated, so there is no need to review it here.

Although the discovery of subject matter content may be an important aspect of these studies, the emphasis is on learning how to develop skills of discovery and inquiry. Thus the focus of learning by discovery has switched from content to process. The work of Suchman[1] and of Bruner, Goodnow, and Austin[2] is of particular importance in studying heuristics. The research of Bruner, Goodnow, and Austin, especially, has influenced later studies of the heuristics of discovery.[3]

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[1] The Elementary School Training Program in Scientific Inquiry.

[2] Jerome S. Bruner, Jacqueline J. Goodnow, and George A. Austin, A Study of Thinking. New York: John Wiley and Sons, 1956.

[3] See, for instance, Joey L. Byers, Strategies and Learning Set in Concept Attainment. Doctor's thesis. Madison: University of Wisconsin, 1961. 101 pp. Abstract: Dissertation Abstracts 22:1904; No. 6, 1961; Lee Sechrest and John Wallace, "Assimilation and Utilization of Information in Concept Attainment under Varying Conditions of

The third use of learning by discovery, teaching the nature of the knowledge discovered, received prominence because of its relationship to current thought about the nature of scientific knowledge. Glass states that one of the main objectives of science education is to teach "the nature of science."[1] To do this Schwab states that the student "needs to understand the conditional truth of scientific knowledge."[2]

The most extensive treatment of the ways to teach the nature of scientific knowledge is contained in a speech made by Schwab in 1961.[3] In this talk Schwab argues that today's citizen must understand the nature of science if he is to influence intelligently public policy dealing with scientific matters. This requires that the old pattern of teaching science as a body of truths be replaced by the modern conception of scientific ideas, "principles of inquiry--conceptual structures--which could be revised when necessary in directions dictated by large complexes of theory, and diverse bodies of data, and numerous criteria

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Information Presentation." Journal of Educational Psychology 53:157-64; August 1962; and Eugene Shore and Lee Sechrest, "Concept Attainment as a Function of Number of Positive Instances Presented." Journal of Educational Psychology 52:303-307; December 1961.

[1] H. Bentley Glass, "Revolution in Biology." BSCS Newsletter 9:7; September 1961.

[2] Joseph J. Schwab, "Some Reflections on Science Education." BSCS Newsletter 9:8; September 1961.

[3] This speech, "The Teaching of Science as Enquiry," is reproduced in Joseph J. Schwab and Paul F. Brandwein, The Teaching of Science. 1961 Englis Lecture in Secondary Education and the 1961 Burton Lecture in Elementary Education. Cambridge, Mass.: Harvard University Press, 1962. pp. 1-103.

of progress in science."[1] Thus there is a continuous revision of scientific knowledge.

In explaining the rationale behind scientific inquiry, Schwab explains that scientific knowledge results from the interaction of two types of inquiry: stable inquiry and fluid inquiry. The first of these is characterized by its investigation of the ramifications of scientific principles. The principles themselves are not questioned; they serve instead as assumptions which guide further research. Fluid inquiry, on the other hand, challenges the principles themselves. It seeks to invent new principles and to test their feasibility. Fluid inquiry is characterized by frustration, failure, and lack of consistent direction. Yet, it is the source of major scientific advances.

Until the present century, fluid inquiry was overshadowed by stable inquiry. Now fluid inquiry has emerged to prominence. The importance of fluid inquiry has greatly increased, but the schools continued to emphasize stable inquiry. The need, then, is to teach science as inquiry so that the nature of scientific knowledge can be taught. By engaging the students in inquiry they can learn about the nature of scientific knowledge.

One aspect of teaching science as inquiry is the utilization of learning by discovery. Learning by discovery is an important part of Schwab's inquiry curriculum. He suggests that laboratory work, for instance, be designed "to lead rather than lag the classroom phase of science teaching."[1] The student can engage in the investigation of scientific problems, attempting to discover new ideas and relationships. As he discovers these new ideas and relationships, the student will come to view all scientific knowledge as the result of discovery and inquiry. Principles and laws are seen as "formulations of the evidence made available by a series of inquiries."[2] It is in this sense that learning by discovery leads to an understanding of the nature of the knowledge discovered.

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[1] Ibid., p. 11.

New Curriculum Proposals Utilizing Learning by Discovery

Learning by discovery has been incorporated into many of the new curriculum proposals. The National Council of Teachers of Mathematics reports that the "discovery approach is utilized in varying degrees by all the new programs [in mathematics] and is a central theme in the UICSM [University of Illinois Committee on School Mathematics] program."[3] Other than the UICSM, the programs spoken of include the School Mathematics Study Group (SMSG), the University of Maryland Mathematics Project (UMMP), the Boston College Mathematics Institute, the Ball State Teachers College Experimental Program, and the Developmental Project in Secondary Mathematics of Southern Illinois University.

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[1] Ibid., p. 52.

[2] Ibid., p. 87.

[3] National Council of Teachers of Mathematics. The Revolution in School Mathematics. Washington, D. C.: The Council, 1961, p. 79.

Kersh[1] reports that both the Madison Project of Syracuse University and the University of Illinois Arithmetic Project (UIAP) emphasize learning by discovery.

Many of the new science curriculum projects employ learning by discovery. Lee[2] reports that the Biological Sciences Curriculum Study (BSCS) uses laboratory work to lead students to make discoveries on their own. In addition many of Schwab's ideas on inquiry have been incorporated into the BSCS materials.[3] The Physical Science Study Committee has also developed laboratory work which accentuates learning by discovery.[4]

Fraser[5] reports that both the Chemical Education Materials Study (CHEM Study) and the Chemical Bond Approach Project (CBA) utilize learning by discovery in their laboratory work.

Although all the curriculum projects mentioned above deal with either mathematics or science, Bruner states that discovery methods are not necessarily limited to "such highly formalized subjects. . . ."[6]

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[1] "Learning by Discovery: A Review of Recent Literature." Paper presented at the Symposium of the American Educational Research Association, Atlantic City, New Jersey, February 20, 1962. p. 4.

[2] Addison E. Lee, "The Experimental Approach in Teaching Biology." American Biology Teacher 23:409; November 1961.

[3] Schwab and Brandwein, The Teaching of Science, pp. 52, 88.

[4] Dorothy M. Fraser, Current Curriculum Studies in Academic Subjects. Washington, D. C.: National Education Association, 1962. pp. 8-9.

[5] Ibid., pp. 13-15.

[6] The Process of Education, p. 21.

He cites some of the Harvard Cognition Projects' experimental work on social studies as evidence of the wide application that can be made of learning by discovery. Appendix J of the present study indicates that at least certain aspects of English, as well as some forms of skill, can be taught by discovery methods. These studies, of course, give no idea of how widely adaptable learning by discovery may or may not be for these areas. All other attempts to locate additional examples of subjects or skills being taught by discovery were unsuccessful.

Instruction for Discovery

Much of the literature on learning by discovery is concerned with methods of instruction for discovery. However, not all of the methods described in the literature satisfy the two criteria of learning by discovery identified earlier in this chapter. These two criteria are (1) that the learner acquire a new idea or concept and (2) that the acquisition of the new information results from the learner's own manipulation and reorganization of data.

Evidence of the satisfaction of these two criteria was obtained by selecting from the literature surveyed statements that indicate that the criteria were met. Because of the length and complexity of some of these sources a brief statement showing that the criteria were met could not be secured. In these cases a reference to the pages of the source which contains information that the criteria are satisfied is provided. Appendix C contains a list of the sources and the evidence showing that they meet the criteria of learning by discovery.

Thirty-six sources were identified. In attempting to identify the various methods of teaching for discovery an analysis was made of each of the different terms used in these sources to identify and differentiate among the various discovery methods. Although most of these sources used discovery in its generic sense, ten specialized terms were used to indicate different methods of teaching for discovery. These ten terms are autonomous discovery, concept attainment, directed discovery, guided discovery, independent discovery, individually derived principles, inquiry, open-ended experiments, self-discovery, and unverbalized awareness.

These terms are used in nineteen of the thirty-six original sources. Appendix D lists the ten terms and their sources. Among these ten terms, however, there is a degree of overlap. For instance, the first term, autonomous discovery, is the same as inquiry, the seventh term.

In an attempt to discriminate further among the various methods of teaching for discovery, each of the above nineteen sources were individually examined to determine how much overlap existed among the ten terms. Unfortunately only ten of the nineteen sources provided definitions of their terms which were adequate enough to allow further discrimination and classification. Appendix E lists these ten sources.

An analysis was made of the differences among the methods of teaching for discovery defined in each of the ten sources. Perhaps the main result of this analysis was the finding that the different methods of teaching for discovery could be distinguished by a single factor, the amount of assistance given to the learner to aid him in making the discovery. This ranged from presenting the learner with some data which establishes a problem situation and asking him to seek an explanation to a very carefully controlled process in which the data is presented in a set pattern organized in such a way as to "lead" the learner to the discovery. The former provides little if any direction for the learner while the latter virtually insures successful discovery.

Instructional methods may be classified by the amount of assistance or direction that they provide for the learner. When classified in this manner, instructional methods may be conceived of as a continuum that ranges from the extreme of absolutely no assistance or direction for the learner to the other extreme of outlining in detail exactly what the learner is to do.

In the case of absolutely no direction the learner is left completely to his own devices. He determines his own problem, selects his own data, and reaches or fails to reach his own conclusions. The only direction is that which resides in the situation itself. In the case of the opposite extreme the learner is subjected to as complete direction by others as is possible. He is told when, where, what, why, and how to learn. No decisions are supposedly left to him.

All methods of teaching for discovery lie between these two extremes. Depending upon the various amounts of direction provided, they constitute a continuum of their own. The examination of the ten terms used to designate methods of instruction for discovery reveals that each of the ten terms may be classified into one of three basic methods. The three basic methods differ from each other in the amount of direction each provides for the learner. Each of the three basic methods of instruction for discovery is discussed below and a list of several examples is given.

The First Method--Autonomous Discovery

In this type of teaching for discovery the learner is presented with a problem situation and little else except instructions concerning standard procedures. The learner is asked to find an explanation or solution but is not told how to go about this task. The teacher or instructor does not attempt to encourage the learner to move in certain directions or adopt certain procedures or strategies.

The learner makes his own decisions about what kinds of evidence to gather, what lines of investigation are to be followed, and what the order of investigation will be. There is, however, some method of verification which the learner can use to determine how well he is doing and when he has made the discovery. These checks usually take the form of testing the relevance of new data to the discovery sought.[1] As the learner determines the relevance of these new data to the problem, he decides for himself what steps are to be taken next.

No attempt is made to arrange or control the learning environment in such a manner that the learner is led to certain conclusions.

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[1] Bruner, Goodnow, and Austin, pp. 67-72.

The environment, rather, is unorganized or, to use a statistical term, randomized. In other words, the learning environment is neutral as far as providing "hints" or suggestions for discovery is concerned.

Examples of this method of teaching for discovery are found in six different sources. Appendix F lists these sources and, where more than one method of teaching for discovery is included, the name of the method classified as autonomous discovery is given following the source.

The Second Method--Guided Discovery

Guided discovery differs from autonomous discovery in that the former involves processes which exert some influence over the decisions and, consequently, the actions of the learner as he attempts to discover an explanation or solution to the problem situation. "Hints" or suggestions are contained in the learning environment.

Normally these hints are provided in several ways. One commonly used method is to control the amount and type of data made available to the learner as he seeks the solution or explanation to the problem situation. The concept attainment studies provide an excellent example of this type of control in their use of positive and negative instances of a concept being sought.[1] Presenting all the needed data to derive a concept can effectively influence the learning process.

A second way of aiding discovery is to control the sequence of data presented. By doing this the teacher or instructor can arrange the data so that they provide a logical pattern of steps leading to the discovery. In other words, the sequence of data is organized so as to parallel the logical sequence of the subject being taught. The learner, of course, is unaware that the presentation of the data is carefully predetermined.

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[1] Ibid., pp. 60-66.

By these two methods the learner is guided toward the desired discovery. It is important, however, to note that the learning environment is manipulated, not the learner. The learner is, of course, indirectly influenced by this manipulation of his environment. Still, he reorganizes his own cognitive structure and reaches his own conclusions.

Five examples of guided discovery were found in the sources. These are presented in Appendix G.

The Third Method--Directed Discovery

This method of teaching for discovery is extensively planned by the teacher or instructor. Not only is the learning environment carefully controlled but the learner is also told the nature of the concept he is to discover. Sometimes the learner is taught part of a principle and is then asked to discover the rest.

Generally both the type and sequence of the data presented to the learner are predetermined. The data to be used are carefully chosen to provide hints about the concept to be discovered. The sequence, likewise, is designed to lead directly to an understanding of the concept. Thus both the type and sequence of the data are programed to direct the learner to the desired concept. These facets are so carefully planned that there is little chance that the concept will not be discovered.

When data are presented to the learner, he is informed that the data are, themselves, organized by either the concept being sought or by a related concept. This focuses the learner's attention on the data and directs his efforts toward the detection of relationships among the data. The other two methods of instruction for discovery do not assist the learner in this manner. He has to discover for himself that such relationships exist.

This method of teaching for discovery differs from expository or reception methods in degree rather than kind. Whereas expository methods usually commence with the generalization and then present evidence as support, the discovery method first presents the evidence and then builds toward the generalization. The learner must identify the generalization for himself; it is never identified for him.

The intent of directed discovery is to provide the learner with a carefully structured series of data that insures the efficient discovery of the concept. The decisions the learner must make about what steps to take next are limited to two or three possibilities by the data themselves. The learner is, in this sense, directed to the discovery.

Directed discovery methods are exemplified in seven sources. These are given in Appendix H.

Summary

The purpose of this chapter was to analyze learning by discovery in order to clarify its present meaning and use in educational circles. The analysis revealed that interest in discovery stems from two main sources: its use in the new curriculum projects such as those described at the Woods Hole Conference, and the current interest in the psychology of learning.

Learning by discovery was found to have a single essential characteristic which distinguishes it from other forms of learning. The learner must acquire new insight by his own reordering or manipulation of data. In other words, he directs the course of his own learning. The definition of learning by discovery developed was that it is a process in which the learner independently reorganizes data or extends his own cognitive structure so that he acquires new insight.

Three different methods of teaching for discovery were identified. The first is autonomous discovery, characterized by the learner's great freedom to conduct his own course of discovery. The second is guided discovery, characterized by the teacher's or instructor's power to control the type, amount, and sequence of data made available to the learner. The third is directed discovery, which is characterized by the extensive control exercised by the teacher or instructor over the data presented to the learner. In addition to controlling the type, amount, and sequence of data, the learner is told that the data are organized so as to illustrate the concept being sought.

Although no definitive study of the rationale of learning by discovery has yet been developed, several basic aspects of its rationale were identified. First, learning by discovery challenges the assumption that someone other than the learner himself can best direct the learning process. Second, discovery learning theory holds that the type of things a person can learn are determined, in large part, by his level of cognitive development. Third, the ability of the learner to verbalize an idea does not mean that the idea is understood. Discovery must precede verbalization. Fourth, learning by discovery establishes a transactional relationship between the content discovered and the process of discovery itself. Thus learning by discovery, according to Taba, resolves the age-old problem of the relative importance of content and process. Each is essential to discovery.

Three common aspects of the strategy of learning by discovery were identified: discovery is initiated by a problem situation; the principle or generalization to be learned is withheld from the learner so that he must discover it for himself; the learner directs his own actions in seeking and reorganizing data to lead him to the discovery.

The proponents of learning by discovery make six claims for its superiority:

1. It increases intellectual potency and cognitive skills.
2. It possesses intrinsic motivation.
3. It teaches the heuristics of discovery.
4. It aids recall and memory.

5. It makes learning more meaningful.

6. It promotes transfer of learning.

A review of the literature discloses that learning by discovery has been used to serve three broad purposes: to teach subject matter content, to teach the heuristics of discovery and inquiry, and to teach the nature of the knowledge discovered. In addition learning by discovery can be used for any two or all three of the above purposes.

The chapter ends with a review of the curriculum proposals which utilize learning by discovery. The proposals were limited to mathematics and science. However, the proponents of learning by discovery say it can be utilized with other types of content. Research studies of discovery learning have used it to teach aspects of English, social studies, and some forms of skill.

CHAPTER VI

EVALUATION OF METHODS OF TEACHING FOR DISCOVERY

Chapter V of this study analyzed and described learning by discovery. One facet of the analysis was the identification and classification of the various instructional methods which have been used to teach for discovery. The purpose of this chapter is to evaluate the effectiveness of these methods of teaching for discovery.

Chapter IV also identified six advantages claimed for learning by discovery. Since these advantages are reputed to result from learning by discovery, they may be used as criteria to evaluate the effectiveness of instructional methods used to teach for discovery. These advantages will be used as sources for the derivation of the evaluative criteria used in this chapter. The advantages claimed for discovery learning are as follows:

1. It promotes meaningful learning.
2. It strengthens and extends intellectual potency and cognitive skills.
3. It is intrinsically motivating.
4. It aids transfer of learning.
5. It teaches the heuristics of discovery.

6. It aids memory processes.

Data for the evaluation were obtained by a review of the current literature on discovery learning. Several characteristics of the studies reviewed limit the nature of the evaluation presented in this chapter. First, since many of these studies do not define their methods of teaching for discovery adequately enough for further classification, it was not possible to make an intensive study of the relative effectiveness of the three specific methods of teaching for discovery identified in Chapter V. However, a limited evaluation of the effectiveness of the three methods is presented, based upon data from the five studies which contained adequate definitions of the terms.

Second, most of the studies compared methods of teaching for discovery with other methods of instruction.[1] The descriptions of the nondiscovery methods of instruction were also not adequate enough to permit further classification according to various types of nondiscovery methods. Therefore, data from these studies can be used only to compare the effectiveness of general rather than specific methods of instruction. Specifically the effectiveness of general methods of teaching for discovery are compared to general methods of nondiscovery instruction.

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[1] These other nondiscovery methods may be distinguished from the methods of teaching for discovery by the fact that the nondiscovery methods provide the learner with the generalization or answer relevant to the problem situation. The methods of teaching for discovery, on the other hand, require that the learner "discover" the answer or generalization for himself. Numerous terms are used for nondiscovery methods. Among the most frequently used ones are rote learning, direct-detailed methods, directed instructions, and directed learning.

Only this broad two-fold comparison is possible from the data available.

From the above it can be seen that the evaluation of the methods of teaching will consist of two parts. The first part of the evaluation will be based upon a comparison of the effectiveness of methods of teaching for discovery and methods of teaching which do not involve discovery. The relative effectiveness of the two diverse methods of instruction were evaluated in terms of the six criteria derived from the advantages claimed for discovery learning.

The second part of the evaluation will consist of applying the same six criteria used in the first part of the evaluation to the three basic methods of instruction for discovery developed in Chapter V. These basic methods are (1) the autonomous method, (2) the guided method, and (3) the directed method. In addition to the six criteria used above, a seventh criterion, the efficiency of the three methods as determined by the length of time and number of steps required to make the discovery, will be used. This criterion was not used in the first part of the evaluation because the proponents of discovery learning concede that their methods of instruction require more time and a greater number of steps than nondiscovery methods of instruction.

Evaluation of the Relative Effectiveness of Methods of Instruction for Discovery and Methods of Instruction Which Do Not Utilize Discovery

In describing the instructional methods used in the studies, it would be more convenient to use shorter terms than the methods of instruction for discovery and the methods of instruction which do not utilize discovery to refer to the two basic forms of instruction being evaluated. Therefore, the methods of instruction for discovery shall be referred to as discovery methods. The methods of instruction which do not utilize discovery shall be referred to as the nondiscovery methods. However, when a descriptive term, such as rote learning, is used as the nondiscovery method in a study, this term will be placed in parentheses immediately after nondiscovery method. This is done to give the reader a clearer idea about the nature of the comparison being made.

Criterion 1--Meaningful Learning

The extent to which learning is meaningful can only be inferred, never directly determined. The studies dealing with this criterion have used three means of inferring the meaningfulness of learning. First, they have used various forms of achievement tests for this purpose. Second, they have observed the learner's behavior in an attempt to find clues of understanding and meaning. Third, they have based their estimates of meaningful learning on the learner's ability to verbalize about what he has learned. Of these three methods of inferring meaning the use of achievement tests is by far the most common.

In the review of the literature eleven studies were located which attempted to determine the influence of discovery on meaningful learning. Brief descriptions and the conclusions of these studies are reported below.

In a study [1] designed to measure the effects of nondiscovery (rote) and discovery methods on concept attainment, 70 high school or college subjects were administered the Hanfmann-Kasain or Vigotsky Block Test. The nondiscovery group memorized the generalization appropriate to the task. The discovery group had to discover the same generalization through observation and manipulation of the materials and the testing of hunches. The results of the study indicated that the discovery method leads to more thorough understanding of the concepts than the nondiscovery method.

Charen[2] compared the achievement of 268 students using both discovery methods (open-ended laboratory experiments) and nondiscovery methods (the traditional laboratory exercises found in a standard chemistry laboratory manual). While using the open-ended experiments the students were expected to formulate their own conclusions. The nondiscovery methods, on the other hand, used the laboratory exercises to verify generalizations which the students had already been taught. The results of the study revealed that the students showed significantly better knowledge of chemical facts and principles when using discovery methods. Tests of critical thinking in chemistry revealed no significant differences between the two methods.

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[1] Finley Carpenter, "The Effects of Different Learning Methods on Concept Formation." Science Education 40:282-85; October 1956.

[2] George Charen, "A Study of the Effect of Open-Ended Experiments in Chemistry on the Achievement of Certain Recognized Objectives of Science Teaching." Paper presented at the Thirty-Sixth Annual Meeting of the National Association for Research in Science Teaching, Washington, D. C., February 20-23, 1963.

In a study of the influence of five different methods of instruction on learning, subjects were asked to identify which of five words did not belong with the other four. The five methods of instruction varied according to the amount of information given to the subjects. Among the results of the study two are related to meaningful learning:

> It makes for better learning if the learner proceeds by a method of active participation involving self-discovery rather than by a method of passive participation involving only recognition or identification of information previously provided to him.
>
> . . . .
>
> The learner obtains as many or more facts, and discovers more correct reasons for them, by a process of self-discovery than by a process of authoritative identification.[1]

Huxtable[2] made a study to compare the achievement of 104 eighth- and ninth-grade students in three areas of English: vocabulary, reading comprehension and interpretation, and creative writing. One group of students, using discovery methods, guided their own work. The other group, using nondiscovery methods, were provided with detailed instructions for their work. The results of the study indicated that there were no significant differences in the achievement of the two groups.

Much the same results were reported by Grote in a study comparing nondiscovery (direct-detailed) and discovery methods of teaching physics. The results indicated that "the group instructed by the direct-detailed method was superior to the directed discovery group as measured by the first initial learning test. However, there was no difference between these groups when measured for initial learning following the second lesson. . . ."[1]

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[1] Chalmers L. Stacey, "The Law of Effect in the Retained Situation with Meaningful Material." In Learning Theory in School Situations. University of Minnesota, Studies in Education, College of Education, No. 2. Minneapolis: University of Minnesota Press, 1949. pp. 100-101.

[2] Zelma T. Huxtable, "Learning Outcomes Following Self-Directed and Formally Guided Responses in Controlled Situations." Journal of Experimental Education 6:406-12; June 1938.

In a related study Moss[2] compared the effectiveness of non-discovery (direct-detailed) and directed discovery methods for teaching letterpress imposition. He concluded that there were no significant differences in the learning which occurred by either method.

Another study, closely related to the two studies above, compared the influence of the same two methods on the learning of orthographic projection principles and skills. The results lead the author to conclude that "the direct-detailed and the directed discovery methods are equally effective in regard to the initial learning of orthographic projection principles and skills."[3]

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[1] Charles N. Grote, A Comparison of the Relative Effectiveness of Direct-Detailed and Directed Discovery Methods of Teaching Selected Principles of Mechanics in the Area of Physics. Doctor's thesis. Urbana: University of Illinois, 1960. 355 pp. Abstract: Dissertation Abstracts 21:3017; No. 10, 1960.

[2] Jerome Moss, Jr., An Experimental Study of the Relative Effectiveness of the Direct-Detailed and the Directed Discovery Methods of Teaching Letterpress Imposition. Doctor's thesis. Urbana: University of Illinois, 1961. 293 pp. Abstract: Dissertation Abstracts 21:2992; No. 10, 1961.

[3] John D. Rowlett, An Experimental Comparison of Direct-Detailed and Directed Discovery Methods of Teaching Orthographic Projection Principles and Skills. Doctor's thesis. Urbana: University of Illinois, 1960. 239 pp. Abstract: Dissertation Abstracts 20:4590; No. 12, 1960.

Research on the Inquiry Training Program has also failed to show that meaningful learning is increased by this type of discovery method. The results of an intensive study of the Program indicate that there is no significant differences between the achievement of the experimental (discovery method) group and the control (nondiscovery method) group. Although there were some differences in favor of the experimental group in regard to the mastery of principles, these differences were also not significant.[1]

A comparative study of the effects of discovery methods and nondiscovery methods (direct instructions) on learning was reported by Ray[2] in 1961. The subjects were ninth-grade boys enrolled in shop classes. The task consisted of learning to use the micrometer. Basing his conclusions on test results, Ray reported that there was no statistically significant difference between the initial learning of the discovery and direct instruction groups.

In a study made in 1958 Kersh attempted to deal directly with the influence of discovery methods on meaningful learning. Defining meaningful learning as the increase in a learner's cognitive understanding or organization, Kersh's experimental design involved three different methods of instruction: a guided discovery method, a directed discovery method, and a nondiscovery method.[1] Subjects using each of the three methods were confronted with the same task, the learning of two rules of addition. Based upon an analysis of test data, Kersh concluded "that the superiority of the discovery procedure of learning over procedures of learning with external direction is not adequately explained in terms of 'meaningful learning.'"[2]

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[1] J. Richard Suchman, The Elementary School Training Program in Scientific Inquiry. Title VII Project Number 216, National Defense Education Act of 1958. Grant No. 7-11-038. Urbana: University of Illinois, 1962. pp. 79-129.

[2] Willis E. Ray, "Pupil Discovery versus Direct Instruction." Journal of Experimental Education 29:271-80; March 1961.

A later study by Kersh used basically the same experimental design. Although the major purpose of the study was to examine the influence of discovery methods on motivation, some highly significant results are reported on the relationship between discovery methods and meaningful learning. In stating his conclusions Kersh observed:

> The data from this present experiment do not support the generalization that learning by a process which involves discovery is necessarily superior to learning by more highly directed processes. Indeed, these data suggest that under certain conditions of learning, highly formalized "lecture-drill" techniques, ordinarily considered sterile and meaningless, produce better results than techniques which attempt to develop "understanding."
>
> . . . .
>
> If it is important only that the task be understood (as is most often the case, presumably), the essential relationships may be learned most economically when taught by another person or teaching program, not by process of self-discovery.[3]

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[1] For a discussion of the meaning of these terms see Chapter V of the present study.

[2] Bert Y. Kersh, "The Adequacy of 'Meaning' as an Explanation for the Superiority of Learning by Independent Discovery." Journal of Educational Psychology 49:292; October 1958.

[3] Bert Y. Kersh, "The Motivating Effect of Learning by Directed Discovery." Journal of Educational Psychology 53:69-71; April 1962.

A summary of the results of these eleven studies shows that three studies indicated that learning by discovery methods does promote meaningful learning. Six studies, however, found that discovery methods offered no advantage over nondiscovery methods. And two studies indicated that meaningful learning is not attributable to the use of discovery methods. These conflicting results lead to the general conclusion that the question of whether or not discovery methods promote meaningful learning better than nondiscovery methods is unsettled. The evidence is inconclusive so no decision may be reached.

Criterion 2--Intellectual Potency and Cognitive Skills

The survey of the professional literature in education failed to uncover a single experimental study of the effects of discovery methods on the development of intellectual and cognitive skills. Therefore, no evidence is available for an evaluation by this criterion.

Criterion 3--Intrinsic Motivation

Research studies on the influence of discovery methods on motivation are few in number. The review of the literature located only three studies dealing with this topic.

In a study conducted primarily to determine the influence of discovery methods on meaningful learning, Kersh also uncovered some findings pertinent to motivation. He found that on retests of achievement the subjects instructed by discovery methods showed substantial increases. Investigations into the reasons for these increases revealed that these subjects had continued to work after the learning periods were over. Evidence of this fact was found in written comments made by the subjects. Several subjects told the author that they had continued to work on the discovery problems, and one subject even tried out some of the problems on his friends. In explaining the results of this study the author reported "that when the learner is forced to rely on his own cognitive capacities, it is more likely that he will become motivated to continue the learning process or to continue practicing the task after the learning period."[1] Kersh also concluded that this increase in motivation was responsible for the superiority in achievement of discovery methods over nondiscovery methods.

In another study closely related to the one just reported Kersh limited his investigation directly to the influence of discovery methods on motivation. Three groups of 30 subjects were taught two rules of arithmetic. One group used discovery methods while the other two groups used nondiscovery methods (directed learning and rote learning). All subjects were given tests of recall and transfer at the end of three days, two weeks, and six weeks. The subjects also completed a questionnaire at each of these three times. The results of the recall and transfer tests revealed that the discovery group did as well as the rote learning group and did better than the directed learning group. The questionnaire indicated that the discovery group continued to practice the learning tasks after the formal learning period had ended. This led Kersh to conclude that "learning by self-discovery is superior to learning with external direction only insofar as it increases student motivation to pursue the learning task. If sufficiently motivated, the student may then continue the learning process autonomously beyond the formal period of learning."[1] Thus, this confirms Kersh's earlier conclusion.

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[1] Kersh, Journal of Educational Psychology 49:292.

The third study, Suchman's research on his Inquiry Training Program, found that the discovery method had a definite influence on students' motivation:

> Our main conclusion from the test results and from our experience with Inquiry Training in many classrooms is that the technique in its present form has a marked effect on the motivation, autonomy and question-asking fluency of children. They clearly enjoy having the freedom and the power to gather their own data in their quest for assimilation.[2]

Although the evidence on the motivating effects of discovery methods is limited to three experimental studies, all three of the studies indicate that discovery methods are intrinsically motivating.

Criterion 4--Transfer of Learning

The survey of the literature uncovered eleven studies of the influence of discovery methods on transfer of learning. By transfer of learning is meant the ability of the learner to utilize information gained in an earlier situation in a related, but not identical, later situation. Comparative tests of transfer resulting from discovery and nondiscovery methods are reviewed below.

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[1] Journal of Educational Psychology 53:70.

[2] Suchman, p. 126.

In 1947 Hendrix conducted a study of the influence of different teaching methods on transfer after a lapse of about two weeks. One of the methods studied, the unverbal awareness procedure, has been identified as a discovery method.[1] The results of Hendrix's investigation indicated that "in every case the highest transfer effects were achieved in the group taught by the unverbalized awareness [discovery] procedure . . . and the lowest transfer effects came from the group taught by . . . the method in which the generalization was stated first, then illustrated, then applied to new problems [nondiscovery method]."[2]

Kersh's study of the influence of discovery methods on meaning revealed some significant information about the influence of these methods on transfer. Transfer was measured four weeks after the conclusion of instruction by a retest designed especially to measure the subjects' ability to apply what they had studied to a similar problem situation. Each subject was required to make a self-report of the processes he used in attempting to solve his problems. A comparison of the tests score and the self-reports led Kersh to conclude that discovery methods increase a learner's motivation, and this, in turn, results in learning that "is more effectively transferred than when the learner is not so motivated."[3] Thus, indirectly discovery methods improve transfer.

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[1] See Appendix C.

[2] Gertrude Hendrix, "A New Clue to Transfer of Training." Elementary School Journal 48:198; December 1947.

[3] Journal of Educational Psychology 49:292.

A study conducted by Haslerud and Meyers investigated the effects of given and individually derived (discovered) principles on transfer. Each of 76 college students used both methods. Transfer was measured a week after all instruction ceased by means of tests on problems similar to the ones studied. The authors reported that the "results give strong support to the postulate . . . that independently derived [discovered] principles are more transferable than those given."[1]

Rowlett's study[2] of nondiscovery (direct-detailed) and directed discovery methods included the investigation of the effectiveness of these two methods for transfer. Subjects for the study were 168 ninth-grade students. Half of them used nondiscovery methods and the remaining half used discovery methods. Based upon a comparison of transfer test scores, the author concluded that the discovery method more effectively promotes transfer after a lapse of six weeks than does the nondiscovery method.

Ray[3] conducted a similar study of the effects of directed-discovery and nondiscovery (direct instruction) methods on the transfer of knowledge of facts and principles of and ability to use the micrometer. The subjects were 1,700 ninth-grade boys. Transfer was measured by a teacher-made test and by observation of the subjects' performance six weeks after all instruction was concluded. The results indicated that the directed discovery method was significantly superior to the nondiscovery method in promoting transfer.

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[1] G. M. Haslerud and Shirley Meyers, "The Transfer Value of Given and Individually Derived Principles." Journal of Educational Psychology 49:297; December 1958.

[2] Dissertation Abstracts 20:4590.

[3] Journal of Experimental Education 29:271-80.

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Kersh[1] made a study of the transfer value of teaching two rules of arithmetic by one discovery and two nondiscovery methods (rote learning and directed learning). Subjects for the study were 90 high school geometry students. Transfer was measured by a test on problems similar to those used during the learning period. Each subject also completed a questionnaire designed to determine the learning processes used by the subject. The test was administered three days, two weeks, and six weeks after all instruction was completed. The results indicated that the rote learning group achieved the best transfer. The discovery group, however, showed better transfer than the directed learning group. Kersh reports that the questionnaire indicated that the discovery group practiced its problems after the conclusion of the learning period. This led Kersh to conclude that this increased motivation of the discovery group explains its superiority over the directed learning group.

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Grote[2] compared the effectiveness of nondiscovery (direct-detailed) and directed discovery methods in promoting the transfer of selected principles of physics. A transfer test was developed by the author and administered to the subjects one and six weeks following instruction. The results indicated that both methods were equally effective in developing transfer.

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[1] Journal of Educational Psychology 53:65-71.

[2] Dissertation Abstracts 21:3016-17.

Moss's study[1] compared the same two methods for effectiveness of transfer of letterpress imposition. Subjects using both methods were given forty-seven minutes of instruction. Transfer was measured by tests developed by the author. The author concluded that both methods were equally effective in promoting transfer.

Craig made a study of the influence of four methods of instruction on learning and transfer. As was shown earlier[2] only three of these methods may be classified as discovery methods. Since the fourth method of instruction gave complete information about the generalization, it is classified as a nondiscovery method. Subjects taught by this method had only to apply the generalization to the test situation. Basing his conclusions of the analysis of transfer test scores for the four methods of instruction, Craig found that the nondiscovery method provided the highest level of transfer. Subjects given all relevant information showed better transfer of learning than did subjects who had to discover all or part of the relevant information. In summarizing his evidence Craig stated that "the most reasonable interpretation of all the evidence available appears to be that subjects of all ages use and benefit from all the help given them in their search for bases determining correct responses."[1]

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[1] Dissertation Abstracts 21:2992.

[2] See Appendixes F, G, and H for the three discovery methods.

Hendrickson and Schroeder[2] conducted an experiment to determine the influence of knowledge of generalization on transfer. One group of subjects used discovery methods to obtain the generalization while the other group was given the generalization. Both groups were considered to have understood the generalization only after they used it successfully in three consecutive problem situations. The results revealed that the nondiscovery methods promoted better transfer of learning.

A study by Kittell was designed to test the relative effectivenexx of three methods of instruction during learning on the transfer of principles. The group taught by discovery methods was told only that a principle was involved in their task. The other two groups were given the principle. The results of the study indicate "that furnishing learners with information in the form of underlying principles promotes transfer . . . of learned principles and may provide the background enabling future discovery of new principles."[3]

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[1] Robert C. Craig, The Transfer Value of Guided Learning. New York: Bureau of Publications, Teachers College, Columbia University, 1953. p. 70.

[2] Gordon Hendrickson and William H. Schroeder, "Transfer of Training in Learning to Hit a Submerged Target." Journal of Educational Psychology 32:205-13; March 1941.

[3] Jack E. Kittell, "An Experimental Study of the Effect of External Direction during Learning on Transfer and Retention of Principles." Journal of Educational Psychology 48:404; November 1957.

Of the eleven studies of transfer six reported findings in favor of discovery methods. Two studies found no difference between the transfer value of discovery methods and nondiscovery methods. Finally, three studies indicated that discovery methods were inferior to nondiscovery methods in promoting transfer of learning. Since the evidence is conflicting, no conclusion can be made in relation to this criterion.

Criterion 5--Heuristics of Discovery

Only two studies of the effects of learning by discovery on the development of heuristics were located. A study conducted by Ashton compared the problem solving abilities of two groups of students. One group used a discovery method designed to make the students self-directive. The other group used the "textbook method," a procedure in which solutions to problems are first demonstrated by the teacher and then the students are assigned similar problems (a nondiscovery method). The results of the study revealed that the discovery method produced greater improvement in problem solving than the nondiscovery method. Ashton concluded that "students benefit by being allowed to find their own solutions if they are helped sufficiently to give them direction and to keep them working, but not so much as to kill initiative."[1]

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[1] Sister Madeleine R. Ashton, Heuristic Methods in Problem Solving in Ninth-Grade Algebra. Doctor's thesis. Stanford: Stanford University, 1962. 125 pp. Abstract: Dissertation Abstracts 22:4289; No. 12, 1962.

The second study was conducted by Suchman to evaluate his Inquiry Training Program, which is specifically designed to teach the heuristics of discovery.[1] In summarizing the results of the Inquiry Training Program Suchman states that he was unable to "arrive at many firm conclusions either in relation to a theory of inquiry or the practical effects of Inquiry Training in a broad or long range sense."[2] However, Suchman does report that the questions asked by children in the Program improved considerably.

The first study found that discovery methods teach the heuristics of discovery better than nondiscovery methods. The second study, however, failed to show that use of a discovery method taught the heuristics of discovery. These results, coupled with the fact that only two studies were located, indicate that no conclusion can be made in regard to this criterion.

Criterion 6--Memory Processes

The effectiveness of discovery methods in improving memory process is stated in terms of their influence on retention. The survey of the literature produced eight studies which attempted to evaluate the effects of discovery methods on retention.

Carpenter's study[3] of the effects of two learning methods revealed that the functional or discovery method promoted greater retention than the nondiscovery (rote) method.

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[1] An explanation of the rationale of Inquiry Training is found in Chapter V.

[2] Suchman, p. 114.

[3] Science Education 40:282-85.

A study by Rowlett[1] comparing nondiscovery (direct-detailed) and directed discovery methods of teaching revealed that the discovery method was superior to the other method in increasing retention of principles and skills.

In a study of the effects of independent discovery methods and nondiscovery methods, Kersh found that the independent discovery methods resulted in superior retention. An analysis of self-reports made by the subjects of their learning processes and methods indicated that those subjects using discovery methods were motivated to continue to practice their work after the formal learning period was completed. This led Kersh to conclude that "the learning becomes more permanent . . . than when the learner is not so motivated."[2]

A later study of the effects of discovery methods on motivation was made by the same author. The results confirmed those reported above: the superiority of discovery methods results from increased motivation. The end result is that "the learner may then . . . remember what he has learned longer. . . ."[3]

Ray conducted a study comparing discovery methods and nondiscovery (direct instruction) methods. He reported that "the directed discovery approach to teaching is superior to direct and detailed instruction with respect to retention of material . . . ."[1]

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[1] Dissertation Abstracts 20:4590.

[2] Journal of Educational Psychology 49:192.

[3] Kersh, Journal of Educational Psychology 53:70.

A study by Grote[2] failed to find any difference in retention resulting from learning by directed discovery and nondiscovery (direct-detailed) methods.

A study by Moss[3] of the same two methods also failed to find any significant differences in retention.

In a study comparing the effects of three methods of instruction on the retention and transfer of principles, Kittell reported that "after periods of two and four weeks subsequent to training, the group receiving an Intermediate amount of direction [a nondiscovery method] retained a greater proportion of learned principles than the other two groups [using discovery methods]."[4]

Five of the eight studies reported that discovery methods aid retention. Two of the studies found no difference between discovery and nondiscovery methods in promoting retention. One study concluded that nondiscovery methods were superior to discovery methods in aiding retention. Although the results of these studies tend to show that discovery aids retention, they do not provide conclusive evidence.

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[1] Journal of Experimental Education 29:280.

[2] Dissertation Abstracts 21:3017.

[3] Dissertation Abstracts 21:2992.

[4] Journal of Educational Psychology 48:404.

Summary of the Relative Effectiveness of Discovery Methods and Nondiscovery Methods of Instruction

Criterion 1--Meaningful Learning. Eleven sources of data were found for this criterion. Since the data conflict, there was not conclusive evidence that one method fostered meaningful learning better than the other.

Criterion 2--Intellectual Potency and Cognitive Skills. No data were available for an evaluation by this criterion.

Criterion 3--Intrinsic Motivation. Three sources of data were found for this criterion. The data indicated that discovery methods have better intrinsic motivation than nondiscovery methods.

Criterion 4--Transfer of Learning. Eleven sources of data were located for this criterion. Because the data are conflicting, no conclusion could be reached as to which method better promoted transfer of learning.

Criterion 5--Heuristics of Discovery. Only two sources of data were found for this criterion. Since the data were ambiguous, no conclusion about the superiority of either method could be reached.

Criterion 6--Improvement of Memory Processes. Only data relevant to retention were found. Eight sources of these data were located. Although there was some conflict among the data, the evidence tended to favor discovery methods over nondiscovery methods.

Of the six criteria used to evaluate the relative effectiveness of the discovery and nondiscovery methods of instruction, no definite statement of the superiority of either of these methods can be made.

However, there was some indication that discovery methods may be slightly more effective than nondiscovery methods in regard to two of the criteria. These criteria are the extent of intrinsic motivation and the promotion of memory processes.

Evaluation of the Relative Effectiveness of Three Methods of Instruction for Discovery

Five studies of the effectiveness of various methods of instruction for discovery were located by the survey of the literature on discovery learning. As was indicated in Chapter V these methods of instruction differ from each other in the amount of direction provided for the learner as he attempts to discover. Chapter V developed a means for classifying the different methods of instruction for discovery into one of three basic methods.

Each of the five studies mentioned above used different terms to identify their methods of instruction for discovery. In order to compare the results of the five studies it is necessary to group similar methods of instruction together. This has been accomplished by organizing the methods according to the three basic methods of instruction developed in Chapter V. Table I shows the classification of these methods. The sources of the methods are also indicated in Table I.

In order to facilitate discussion, the various instructional methods used in the five studies will be referred to as autonomous, guided, or directed rather than by the terms used in the studies themselves. Thus, Bruner's Random method will be called the autonomous method, as will Stacey's Method A.

TABLE 5

CLASSIFICATION OF METHODS OF INSTRUCTION FOR DISCOVERY USED IN FIVE STUDIES

Study	Basic methods of instruction for discovery		
	Autonomous	Guided	Directed
Bruner[a]	Random	Ordered	
Craig[b]	Nonguidance	Guidance G	Guidance GX
Kersh[c]		No-help	Directed-reference
Sechrest[d]	Condition I	Conditions II and III	
Stacey[e]	Method A	Method B	

[a] Jerome S. Bruner, Jacqueline J. Goodnow, and George A. Austin, *A Study of Thinking*. New York: John Wiley and Sons, 1956.

[b] *The Transfer Value of Guided Learning*.

[c] *Journal of Educational Psychology* 49:282-92.

[d] Lee Sechrest and John Wallace, "Assimilation and Utilization of Information in Concept Attainment under Varying Conditions of Information Presentation." *Journal of Educational Psychology* 53:157-64; August 1962.

[e] *Learning Theory in School Situations*. pp. 74-103.

The three basic methods of instruction for discovery will be evaluated by seven criteria. The same six as used above in the evaluation of discovery methods and nondiscovery methods will be retained. The seventh criterion is the length of time and number of steps required for discovery. This criterion was not used in the above evaluation because the proponents of discovery methods conceded that their methods required more time and steps than nondiscovery methods. Because of the importance of time and the degree of complication required by an instructional method, it is important to determine the relative efficiency of the three basic discovery methods in these respects. For this reason the seventh criterion was adopted.

Criterion 1--Meaningful Learning

Stacey compared the effects on achievement of both the autonomous and guided methods of instruction for discovery. Achievement was measured by two means: (1) objective tests scores, and (2) the subject's ability to give the proper reasons for the correct responses on the objective tests. The analysis of these data produced ambiguous results. One set of test data indicated that the autonomous method was superior to the guided method. Two other sets of test data indicated that there were no significant differences in achievement under the two methods.[1]

Criterion 2--Intellectual Potency and Cognitive Skills

No data were available for an evaluation by this criterion.

Criterion 3--Intrinsic Motivation

No data were available for an evaluation by this criterion.

Criterion 4--Transfer of Learning

A study by Craig compared all three basic methods of teaching for discovery. Since his study dealt with transfer, he evaluated the methods in terms of their effectiveness in promoting transfer. The subjects were 200 male college graduates. The learning task consisted of discovering the principles which determined how four of five words in an item are related. The autonomous group was told only that one word did not belong with the other four. The items were presented to this group in random order. Although the guided group received the same instructions as the autonomous group, the order of the items presented to the guided group was organized so that all items based on the same principle were presented together. The organization of the items presented to the directed groups was the same as that provided for the guided group. However, the directed group was informed that there were principles which determined the relationships among the words in each item, and that all items based on the same principle were grouped together. Transfer for the three groups was measured by a test utilizing similar problems. Of the three methods the directed method produced the best transfer. "The amount of transfer of training increases as more and more clues are provided to aid discovery of the bases for correct responses."[1] The results also indicated that the more difficult a task, the more significant are the effects of increased direction on aiding transfer.

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[1] Stacey, Learning Theory in School Situations. pp. 98-100.

Kersh[2] made a study comparing the influence of the guided and directed methods on transfer. The results indicated that the guided method of instruction promoted better transfer of learning than the directed method.

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[1] The Transfer Value of Guided Learning. p. 66.

[2] Journal of Educational Psychology 49:282-92.

Since the results of these two studies are conflicting, no conclusion can be made about the relative effectiveness of these methods in promoting transfer.

Criterion 5--Heuristics of Discovery

No data were available for an evaluation by this criterion.

Criterion 6--Improvement of Memory Processes

The data found are relevant to retention only. The study by Kersh[1] reported under Criterion 2 also compared the effects of the guided and directed methods of instruction on retention. He concluded that the guided method resulted in better retention than the directed method.

Criterion 7--Time and Steps Required for Discovery

In evaluating the effectiveness of two of the basic methods of teaching for discovery Sechrest and Wallace[2] reported that the autonomous and guided methods were equally effective in producing discovery in terms of the number of steps required to reach the solution.

Bruner[3] reports a study in which a comparison was made of the efficiency of the autonomous and guided methods of instruction.

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[1] Journal of Educational Psychology 49:282-92.

[2] Journal of Educational Psychology 53:162-63.

[3] A Study of Thinking. pp. 99-102.

Subjects using the guided method consistently attained their discoveries faster and with fewer steps than the subjects using autonomous methods.

No conclusions about the relative effectiveness of the autonomous and guided methods can be reached because of the ambiguous nature of the data.

In summary, the data from these five sources have failed to establish, on the basis of the seven criteria used, the superiority of one method over the others. This conclusion stems from three facts: (1) the scarcity of data, (2) the nature of the data (few studies compared all three methods), and (3) conflicts or ambiguity within the data.

Summary

This chapter evaluated the effectiveness of methods of instruction for discovery. The evaluation was divided into two parts. The first part compared the effectiveness of methods of instruction for discovery and methods of instruction which do not utilize discovery. The limitations of the data did not permit specific types of methods of instruction for discovery to be compared to specific types of methods of instruction which did not utilize discovery. The comparison was made for the general methods of instruction for discovery and the general methods of instruction which do not utilize discovery.

The two diverse approaches to instruction were evaluated by six criteria derived from the advantages claimed for discovery learning. The six criteria are (1) the fostering of meaningful learning, (2) the strengthening and extension of intellectual potency and cognitive skills,

(3) the extent of intrinsic motivation, (4) the promotion of transfer of learning, (5) the teaching of the heuristics of discovery, and (6) the improvement of memory processes. Data for the evaluation were gathered by a review of current literature on learning by discovery.

The results of the evaluation were largely inconclusive. No definite statement of the superiority or lack of superiority of the methods of instruction for discovery as compared to the methods of instruction which do not utilize discovery could be made for any of the six criteria. However, there was some indication that methods of instruction for discovery may be slightly more effective than methods of instruction which do not utilize discovery in regard to intrinsic motivation and the promotion of memory processes.

The second part of the evaluation compared the effectiveness of three basic methods of instruction for discovery. The three basic methods, the autonomous, the guided, and the directed, were evaluated by the same six criteria used above. In addition a seventh criterion, the length of time and number of steps required for discovery, was used. Data for this evaluation were also gathered by a review of the literature on discovery learning.

The evaluation failed to establish the superiority of one method over the other two for any of the criteria used. The failure of the evaluation to find any method superior to the others in relation to a single criterion is believed to result from three limitations of the data: (1) the scarcity of data, (2) the nature of the data (few sources compared all three basic methods of instruction for discovery), and (3) conflicts or ambiguity within the data.

CHAPTER VII

A CRITICAL SUMMARY

The efforts to improve the school curriculum by emphasis on disciplinary structure and learning by discovery have been widespread and well financed. Materials developed by the Biological Sciences Curriculum Study, for instance, have been used by approximately a thousand teachers and one hundred sixty thousand students. The School Mathematics Study Group's materials have been used by over three thousand teachers and one hundred thousand students. The federal funds made available to finance these new projects amount to millions of dollars. As of 1961 grants to the School Mathematics Study Group alone equaled $4,284,200.

Support for this movement was voiced in the report of the President's Commission on National Goals. Gardner proposes that "by 1970 the teaching of every subject from the elementary grades through high school should have received intensive reappraisal by teams composed of (a) the best minds in the subject-matter field, (b) curriculum specialists, and (c) the most experienced elementary or secondary school teachers of the subject."[1] As an example of such reappraisal

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[1] John W. Gardner, "National Goals in Education." Goals for Americans. (The President's Commission on National Goals.) Spectrum Book S-AA-3. Englewood Cliffs, N. J.: Prentice-Hall, 1960. Chapter 3, p. 86.

Gardner suggests the work undertaken in mathematics by the National Science Foundation, the College Entrance Examination Board, and the University of Illinois. These groups financed or advised some of the disciplinary projects described in The Process of Education.

Chapters II through VI of this study have analyzed, described, and evaluated the curriculum design approach set forth in The Process of Education. This final chapter will (1) outline some of the implications of this approach for curriculum design, (2) present and criticize the reactions to this design made by curriculum experts, and (3) present the writer's own critique of the design.

Implications for Curriculum Design

The implications of the disciplinary structure approach to curriculum design are grouped according to the four traditional aspects of curriculum design: organization, selection, scope, and sequence.

Organization

Curriculum organization is based in part upon the goals and purposes set for education. Therefore, it is necessary to have some understanding of the educational purposes advocated by the proponents of teaching disciplinary structure. Such an understanding would help to clarify the reasons why certain curriculum innovations are supported by those favoring the disciplinary structure approach to curriculum design.

In reporting for the Woods Hole Conference Bruner writes that "a curriculum ought to be built around the great issues, principles and values that a society deems worthy of the continual concern of its members."[1] The members of the conference recognize the relationship of education to the complexities of modern life. Certainly they are aware of the rapidly changing social, economic, political, and cultural conditions characteristic of today's world. They agree that education must concern itself with these conditions. Education must contribute to the production of scholars, scientists, statesmen. The needs for citizenship education, too, must be taken into account. The conference also recognized that education must provide for needs other than just the intellectual ones. The "schools must also contribute to the social and emotional development of the child if they are to fulfill their function of education for life in a democratic community and for fruitful family life."[2] The scholars and scientists are aware of the broader educational needs of our society.

Curriculum design based on disciplinary structure is also closely attuned to another widespread concern of our time, the concern for educational excellence. By educational excellence is meant intellectual development of each student. Recent criticism of education has dwelt at length on the need for greater intellectual emphasis in the schools. The projects and theory examined in this chapter clearly focus on the intellectual aspects of education. This is proudly stated by the supporters of the disciplinary structure approach to curriculum design. This approach, they believe, will put the educational focus on intellectual development, a position which, they claim, the schools have deserted.

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[1] Jerome S. Bruner, The Process of Education. Cambridge, Mass.: Harvard University Press, 1960. p. 52.

[2] Ibid., p. 9.

All the proponents of teaching disciplinary structure, however, do not assert that intellectual development is the only goal of education. Proof of this was given above and is supported by the following quotation found early in The Process of Education: "If the emphasis in what follows is principally on the intellectual side of education, it is not that the other objectives of education are less important."[1] While declaring that there are other important goals of education, this statement lucidly affirms that a curriculum based on disciplinary structure will emphasize the intellectual aspects of education. The other educational goals must be achieved through other means.

Several important implications for curriculum design are implied by the above statements. First, to the extent that the total school curriculum is founded on disciplinary structure that curriculum will emphasize the intellectual aspects of education. This leads directly to the second implication. If other educational purposes besides the intellectual ones are to be fostered by the schools, other bases for curriculum design than just disciplinary structure must be adopted. Disciplinary structure cannot serve as the sole basis for curriculum design, for it cannot provide for all of the purposes our society demands of its schools.

As further study of the curriculum implications of disciplinary structure is undertaken, it must be remembered that the educational purpose of this viewpoint is restricted to the fostering of the intellectual development of the students.

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[1] Ibid.

If the goal of this approach to curriculum design is limited to intellectual development, it follows that only the academic subjects are completely compatible with the curriculum design outlined by the Woods Hole Conference. Mathematics, science, languages, English, history, and similar subjects may be effectively taught by emphasizing their structure. On the other hand, such an approach to the teaching of physical education, shop, homemaking, music (unless pursued for intellectual rather than functional purposes), and other non-academic courses would be wholly inappropriate. Therefore, the curriculum design being studied is applicable only to that part of the total school curriculum concerned with the academic subjects.

The pattern of curriculum organization implied by disciplinary structure is separate subjects. Each academic subject would be taught without integration with the other subjects. There would, of course, be some recognition of the connections between certain subjects. Such recognition was made by each of the three proposals examined earlier in this chapter. Yet the extent of these connections would be small.

Mention was also made earlier in this study that some subjects presently taught separately could probably be integrated to the extent that each of them shared a common structure. The mathematicians have successfully combined many of the elements of algebra, arithmetic, and geometry in their SMSG curriculum. At the Woods Hole Conference there were some suggestions that this would be possible in other areas of the curriculum. It was felt that some aspects of structure might be wide enough to include content from several of the sciences. The specific example was a type of "general science." However, the topic was dropped without further discussion.

Although possibilities exist for further integration of subjects, the curriculum organization presently being used remains separate subjects.

Selection

The separate subjects curriculum organization is undoubtedly reinforced by the procedure used to select the content of the curriculum. Since the content is selected by subject-matter specialists, it is natural that they would follow a separate subjects approach. Needless to say the traditional curriculum, which was also subject centered, is easily modified to handle the new projects, a characteristic which allows a smooth transition to the new design.

The scholars and scientists identify the structure of their respective disciplines. Next they select the content which they feel will best teach the structure. Because the structure itself is of a theoretical and abstract nature, the content also tends to be abstract and theoretical. The place of application and technology in course content is sharply curtailed.

Special care is taken to see that the content of the courses is up to date and reflects the current structure of each discipline.

Finally, the content may be selected with students of any ability level in mind. However, the three projects examined in the chapter all report that they selected their content for pupils of average ability.

Sequence

Sequence includes consideration of both grade placement and the order in which educational experiences are presented to the learner. The choice of how best to determine sequence will fall somewhere on a continuum extending from the adjustment of the content to fit the student to the preparation of the student to learn the content. The latter position concerns itself with getting the student ready for the learning while the former takes the opposite viewpoint, adjusting the learning to the child.

The curriculum sequence suggested by the Woods Hole Conference does not fall at either extreme of the continuum. However, the sequence advocated does rest much nearer the end of the continuum which holds that the student should be prepared for the content. Evidence to support this view of sequence is provided by two of the assumptions made by the Woods Hole C onference in regard to the nature of learning. The first assumption is that any idea can be taught to any child at any age if the idea is translated into the appropriate thought patterns used by the child. The second assumption asserts that intellectual activity is the same everywhere, regardless of the educational level or maturity of the learner. From these assumptions it follows that the real problem of sequence, as far as subject matter is concerned, is to discover how to translate the ideas to be taught into the thought patterns of the learners. This is the only way in which the content has to be adjusted to the learner. This is accomplished through the process of readiness.

"Readiness," reports Bruner, "is a function not so much of maturation--which is not to say that maturation is not important--but rather of our intentions and our skill at translation of ideas into the language and concepts of the age we are teaching."[1] The Woods Hole Conference identified three general ideas germane to readiness: (1) the process of intellectual development, (2) the act of learning, and (3) the spiral curriculum. Since these ideas were fully discussed in Chapter II of this study, they do not require more than a brief review.

The process of intellectual development is characterized by three stages: (1) preoperation, which is concerned largely with the relationships between experience and action, (2) concrete operations, characterized by rapidly developing internal thought processes, and (3) formal operations, which marks the attainment of adult mental processes. The first stage, the preoperational, ends about age six. The concrete operations stage ends at about ages ten through fourteen.

To those who advocate the teaching of disciplinary structure the significance of their plan for sequence is that it helps the child to pass through the first two stages of intellectual development more rapidly. They explain their position in this way:

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[1] Jerome S. Bruner, "On Learning Mathematics." Mathematics Teacher 53:617; December 1960.

> The intellectual development of the child is no clockwork sequence of events; it also responds to influences from the environment, notably the school environment. Thus instruction in scientific ideas, even at the elementary level, need not follow slavishly the natural course of cognitive development in the child. It can also lead intellectual development by providing challenging but usable opportunities for the child to forge ahead in his development. Experience has shown that it is worth the effort to provide the growing child with problems that tempt him into [the] next stages of development.[1]

The rate of intellectual development can be increased, it is believed, by teaching structure, for structure provides the means of tempting the child into the next stage of development. This is accomplished in two ways. First, many of the basic ideas of a discipline are simple and can be grasped intuitively by the child. Second, the basic ideas comprising the structure lead naturally to a broadening and deepening of understanding as they are reintroduced by the spiral curriculum in gradually more complex forms. The intuitive aspects of structure are taught first in simple, nonformal terms. This is accomplished when the formal patterns of the structure are translated into the appropriate language and thought patterns of the child. It is a waste of time and effort to attempt to teach the basic ideas in formalized terms which do not match the intellectual development of the learner. By following this procedure, the members of the Woods Hole Conference believe intellectual growth can be accelerated.

The act of learning, the second general idea about readiness, is concerned with learning episodes. These episodes should be adjusted to the ability and interest of the learner. Teaching the structure of a subject permits the easy adjustment of learning episodes. First, teaching structure insures that the learner will see the importance of the new material to what is already known. Secondly, the structure, like any other material being taught, can be shortened or lengthened as the occasion requires. However, "it also seems reasonable that the more one has a sense of the structure of a subject, the more densely packed and longer a learning episode one can get through without fatigue."[1] Here is another way that teaching structure aids intellectual development. Finally, teaching structure removes the need for extrinsic rewards. The sense and excitement of using one's intellectual powers provide the best motivation for learning. It is just this type of motivation that teaching the structure of a subject provides.[2]

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[1] Bruner, The Process of Education, p. 39.

The final general idea about readiness, the spiral curriculum, relates directly to sequence. Once the structure of a subject has been identified and translated into the thought patterns of the learner the "curriculum as it develops should revisit these basic ideas repeatedly, building upon them until the student has grasped the full formal apparatus that goes with them."[3] The spiral curriculum, then, is the means adopted to refine progressively and to formalize the teaching of structure.

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[1] Ibid., p. 51.

[2] A fuller explanation of motivation of this nature is found in Robert W. White, "Motivation Reconsidered: The Concept of Competence." Psychological Review 66:297-333; September 1959.

[3] Bruner, The Process of Education, p. 13.

Ideas introduced in the early grades will be repeated at deeper levels later, when additional ramifications will also be explored. Gradually the complexities of the subject will be taught.

Another major factor influencing sequence is the logical unity of the subject. This logical unity provides the structure of such subjects as mathematics and science. Therefore, these courses will be presented in logical sequence in order that the cohesiveness of the structure may be taught. Subjects such as literature and art, which are characterized by a metaphoric rather than logical structure present a problem. Indeed, to date there has been no identification of the structure of these subjects by the scholars. In any event it is clear that logic probably will not determine the sequence.

The grade placement of the various subjects taught according to structure will probably follow the traditional pattern of the old curriculum. For instance, the BSCS material is used in grade ten, PSSC physics in grade twelve, and SMSG presents algebra in grade nine and geometry in the tenth grade. There have, of course, been some modifications and changes in sequence and grade level, but, by and large, the new projects adhere to the conventional grade levels.

Scope

The scope of the courses emphasizing disciplinary structure leads to several important implications. First, no attempt is made to cover all the information relevant to a subject. The explosion of knowledge occurring in virtually every field renders such a goal impossible. The teaching of structure makes such a goal unnecessary. "Subject matter presented so as to emphasize its structure will perforce be of that generative kind that permits reconstruction of the details or, at very least, prepares a place into which the details when encountered, can be put."[1] The latter part of this quotation clearly implies that structure can be taught without covering all the details of a subject.

Only those ideas closely related to structure are taught. Other ideas are eliminated. Application and technology, for instance, are greatly curtailed, if not entirely eliminated, from the proposals presented earlier in this chapter. Breadth of scope is sacrificed so that more depth can be achieved. In one respect, however, scope is expanded. This is done so that the discipline can be kept up to date. New ideas and information are added to the course as they are developed by the specialists. Stated briefly, scope is determined by structure.

Summary of Implications

The implications of teaching disciplinary structure for curriculum organization are:

1. Since it stresses only the intellectual goals of education, the disciplinary structure curriculum approach cannot serve as the sole basis for curriculum design if society has other educational goals in addition to the intellectual goals.

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[1] Jerome S. Bruner, On Knowing. Cambridge, Mass.: Belknap Press of Harvard University Press, 1962, p. 121.

2. Disciplinary structure curriculum approach is applicable only to the academic subjects, not all subjects included in the school curriculum.

3. In order for the other goals of the school to be accomplished it would be necessary to have other bases for curriculum design in addition to that of disciplinary structure.

4. The pattern of curriculum organization implied by the teaching of disciplinary structure is that of separate subjects.

5. Certain subjects presently taught separately could be integrated to the extent that they share a common structure.

The implications of teaching disciplinary structure for content selection are:

1. Content would be selected on the basis of its significance to an organized field of knowledge.

2. The content selected is organized into conceptual schemes which comprise the structure of the disciplines.

3. The structure of the disciplines consists of abstract and theoretical principles.

4. Scholars and scientists would identify the structure and select the content of their respective disciplines.

5. The content selected would reflect the structure of the discipline as identified by the scholars and scientists.

6. Specific items of content may vary within different courses teaching the same discipline. Uniformity of structure does not have to result in uniformity of specific content.

7. The content of each discipline would be continuously revised so as to be always up to date.

8. The content may be selected for students of any ability level; however, the usual procedure is to select content for students of average ability.

The implications of teaching disciplinary structure for sequence are as follows:

1. Sequence is derived from the logical unity of the structure identified by the scholars and scientists.

2. The sequence is designed according to the research of Piaget and Inhelder.

3. The spiral curriculum is one of the main methods of dealing with sequence.

4. Sequence is accelerated by teaching structure, which allows material to be learned quicker and earlier.

5. Grade placement of subjects tends to follow the traditional grade levels.

6. Teachers assist the subject-matter specialists in preparing the sequence of the subjects.

The implications of teaching disciplinary structure for scope are as follows:

1. Depth rather than breadth of scope is emphasized.

2. Scope is achieved by teaching structure rather than specific isolated details of content.

3. Technology and application are eliminated from the scope of most disciplines.

4. Scope will be expanded from time to time in order to keep the content up to date.

5. All the content selected for a subject must be taught if all aspects of the structure are to be effectively covered.

6. Teaching the structure of a subject provides for the elimination of many items of content from the scope of the disciplines.

Reactions of Curriculum Experts to Disciplinary Structure Curriculum Design

Perhaps the most surprising discovery made as the professional literature was surveyed was the scarcity of published reactions by curriculum experts to the disciplinary structure curriculum design. For the most part educators have remained silent about the new curriculum projects. The professional journals are filled with articles about the new projects; yet the vast majority of the articles are expository or descriptive in nature. Only recently have the educators begun to express themselves about the disciplinary structure curriculum design.

In February of 1962 the National Education Association published a report[1] of a disciplines seminar which was held at the NEA Center in Washington, D. C., on June 15, 16, and 17, 1961. The purpose of the seminar was

> to facilitate study and effective use of the disciplines by (a) focusing upon those fundamental ideas and methods of inquiry from selected fields of study which should be in the mainstream of the instructional program of the public schools, and (b) exploring frontier thinking and research on the nature of knowledge and ways of knowing.[2]

As a result of the seminar several conclusions about the relationship between the schools and the disciplines emerged. The most pertinent conclusion, in terms of the purpose of this chapter, was the recognition of the "increased involvement of academic scholars in problems of teacher education and curriculum content."[3] Thus the professional educators recognized that the subject-matter specialists, scholars and scientists, have a role in the formulation of school curriculum. One of the unresolved problems acknowledged by the seminar is the relationships among the various disciplines and the establishment of a unified and balanced curriculum.[1] The seminar closed with the acknowledgement of the need for cooperation between professional educators and the scholars. This publication, however, made no attempt whatever to have educators react to the disciplinary structure approach to curriculum design. It does provide evidence that professional educators were aware of the importance of the work of the scholars and scientists and their increasing influence on the school program.

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[1] National Education Association, The Scholars Look at the Schools. Washington, D. C.: The Association, 1962.

[2] Ibid., pp. 1-2.

[3] Ibid., p. 54.

An article by Chase, Dean of the Graduate School of Education, University of Chicago, outlines some of the implications of the new projects for public education. These implications which deal with changes in "educational objectives, curriculum theory, the practice of teaching, and the organization and administration of schools"[2] have been discussed in Chapter II of this study. Perhaps the most relevant idea to the present chapter is Chase's comments on the increasing influence of the federal government on educational practice and policy. Chase makes intimations about a national curriculum but evades the issue although he does support federal aid to education.

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[1] Ibid., pp. 49-52.

[2] Francis S. Chase, "Some Effects of Current Curriculum Projects on Educational Policy and Practice." School Review 70:132; Spring 1962.

In June of 1962 the National Education Association published a booklet[1] describing the new curriculum projects. No attempt was made to evaluate any of the projects. The author explains that the "purpose is to provide information about this recent development in American education, not to evaluate or to make recommendations concerning any particular project."[2] However the final chapter presents four principles to aid educators in "making wise, effective use of proposed curriculum plans and materials."[3] These four principles are as follows:

> 1. Following a systematic procedure for utilizing the results of special curriculum projects will be helpful in applying recommendations from the projects or in selecting among different materials for a particular subject.
> 2. In applying the proposals of special curriculum projects, balance and continuity in the students' total school experience should be maintained.
> 3. The public schools have an obligation to continue their efforts to provide effective education for all children and growth as the results of the special curriculum projects are utilized.
> 4. Opportunities for advanced study should be provided for teachers to facilitate their development of courses that utilize new approaches and new content.[4]

These principles, of course, provide some insight into the reactions of professional educators. Certainly they indicate an attitude of restraint and careful evaluation. Also indicated is a concern for balance in the total school program. This implies that there is some danger of overemphasis on certain subjects and a corresponding neglect of others. The third principle listed implies that there is a danger that the new program may not be suitable for all students. Thus, although no attempt is made to evaluate the new projects, a note of caution is clearly evident in these reactions.

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[1] Dorothy M. Fraser, Current Curriculum Studies in Academic Subjects. Washington, D. C.: National Education Association, 1962.

[2] Ibid., p. i.

[3] Ibid., p. 87.

[4] Ibid., pp. 86-93.

Specific reactions to the projects have been expressed by few educators. Several educators, however, have complained about the emphasis which the new mathematics projects place on the abstract structure of mathematics.[1] Glennon especially warns against a loss of balance in the mathematics program of the school resulting from the overemphasis on abstractions. He also cautions that adequate research is not yet available to evaluate properly the new projects.

Hughes[2] expresses concern about certain fundamental changes in educational practice resulting from the new projects based on disciplinary structure. First, he is concerned about the educational objective implied by these projects, preparing citizens to take their place in a scientific society. Hughes's point is a simple one: the emphasis on science is leading to the neglect of other nonscientific human talents. The importance of the individual's interest and talent is becoming subservient to the needs of society. Second, Hughes questions the assumption that any subject can be taught to any child at any age in some intellectually honest form.

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[1] Vincent J. Glennon, "Balanced Progress in School Mathematics." (Editorial) Educational Leadership 19:354-58; March 1962. Howard F. Fehr, "Trends in the Teaching of Arithmetic." Frontiers of Elementary Education VII. (Edited by Vincent J. Glennon.) Proceedings of a Conference on Elementary Education. Syracuse, N. Y.: Syracuse University Press, 1960. Chapter 3, pp. 29-37. Phillip S. Jones, "The Mathematics Teacher's Dilemma." Bulletin of Education (University of Michigan) 30:65-72; January 1959.

[2] Phillip Hughes, "Decisions and Curriculum Design." Educational Theory 13:187-92; July 1962.

Miel,[1] in a recent publication, suggests nine guidelines that educators should keep in mind when they are considering the proposals based on the disciplinary structure approach to curriculum design. These nine guidelines are paraphrased below:

1. No general agreements have been reached on what a discipline is or on which disciplines should be included in the school curriculum.

2. The scholars or scientists cannot easily agree on the structure of their respective fields. In addition the same methods of structuring the natural sciences is not likely to be applicable to other fields.

3. The structure of a discipline presents knowledge as abstract and static and fails to give the student any idea of how the knowledge itself was produced. The method of inquiry of the discipline is neglected.

4. The structure of a discipline is likely to change from time to time.

5. Since it is impossible to teach the complete structure of a discipline at once, it is necessary to assist students in learning the structure gradually over a period of time.

6. Not all students require the same degree of knowledge of disciplinary structure.

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[1] Alice Miel, "Knowledge and the Curriculum." New Insights into the Curriculum. 1963 Yearbook. Washington, D. C.: The Association for Supervision and Curriculum Development, a Department of the National Education Association, 1963. Chapter 4, pp. 71-104.

7. Teaching the structure of a discipline may lead to emphasizing those subjects most easily structured, such as mathematics and science. Other subjects might be assigned secondary positions in the curriculum.

8. The proponents of teaching the structure of the disciplines have not developed a unified plan or theory of curriculum organization.

9. The proponents of teaching the structure of the disciplines have not indicated the relationships to be developed among the various disciplines nor have they considered the relationships between the disciplines and the school curriculum as a whole.

No other reactions of curriculum experts to the proposals were located.

Summary of Reactions

From the above discussion the following list of reactions was developed:

1. The curriculum experts accept the fact that the subject-matter specialists have a bona fide role in curriculum design.

2. The educators are concerned about the implications of the new projects for a national curriculum.

3. The educators propose an attitude of restraint and careful evaluation in considering the new projects.

4. They have expressed concern about the balance of the total school curriculum.

5. They have expressed concern about the suitability of the new projects for all students.

6. They acknowledge the need for teachers of the new projects to receive special instruction to equip them to teach the new material adequately.

7. The educators question the emphasis on abstraction to the point that application and practical aspects of a subject are greatly reduced or omitted altogether.

8. They are concerned about the possibility of the subservience of individual talents and interests to national needs.

9. They believe that there are few agreements about what a discipline is and which ones should be included in the school curriculum.

10. They feel that the methods of structuring mathematics and science may not be appropriate to other subjects, especially the arts and humanities.

11. The educators believe that teaching the structure of a discipline represents knowledge as abstract and static, and results in the lack of an understanding of the method of inquiry of a discipline.

12. They believe that the structure of a discipline changes.

13. They feel that it is necessary to teach students the structure of a discipline gradually over a period of time.

14. They do not feel that all students require the same degree of knowledge of disciplinary structure.

15. The educators fear that emphasizing the structure of a discipline may lead to emphasizing those subjects most easily structured.

16. They call attention to the fact that the proponents of teaching structure have not developed a unified plan for curriculum organization.

17. The educators also note that no plan has been developed to relate the disciplines either to each other or to the total school curriculum.

Critique of the Reactions of Curriculum Experts

The writer has never uncovered any information which indicated that the curriculum experts ever objected to having subject-matter specialists participate in designing that part of the curriculum which pertains to their subject-matter area. There is no issue on this point.

Implications of the new projects for a national curriculum are of concern to some educators. The point is raised that the federal aid that is given to these projects will eventually lead to federal control and a national curriculum. The National Science Foundation states that it "will generally support more than one approach in any scientific discipline, provided each one is well conceived, is appropriately staffed, and shows promise of wide usefulness. Thus, three approaches to biology are being developed by the Biological Sciences Curriculum Study, and two chemistry projects are receiving support."[1] Although federal funds were made available for only the School Mathematics Study Group (SMSG), six other mathematics projects are being developed through aid from private foundations and other nongovernmental sources.

The director of the biology project states that "there is no national control of curriculum in America. Responsible authorities are as free to adopt or reject the textbooks of the major curriculum studies as they are to adopt or reject the textbooks of the major publishing houses."[2] Similar views have also been expressed by representatives of SMSG and the Physical Science Study Committee.[3]

These facts and statements plus the local control of education characteristic of American schools indicate that there is little danger of the establishment of a national curriculum.

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[1] National Science Foundation, Division of Scientific Personnel and Education, "The Role of the National Science Foundation in Course Content Improvement in Secondary Schools." School Review 70:13; Spring 1962.

[2] Arnold B. Grobman, "In My Opinion: National Curricula." American Biology Teacher 24:484; November 1962.

[3] Edward G. Begle, "The School Mathematics Study Group." Mathematics Teacher 51:617; December 1958. E. P. Little, "A Commentary." (Symposium) Harvard Educational Review 29:34; Winter 1959.

An attitude of restraint and careful evaluation proposed by the curriculum experts is clearly supported by the evidence gathered for this study. At present there is little evidence to show that the new projects are superior to the old courses. Indeed, ways to evaluate the new projects are still being developed. In addition there needs to be careful consideration given to the aims and purposes of the new projects to determine how appropriate these aims are for the school and the community it serves.

Concern about the balance of the total school curriculum also seems justified. Most of the new projects are structured from the point of view of the scholars or scientists. This plus the elimination or reduction of technology and application result in the emphasis on abstraction and theory. Research needs to be conducted to determine how this might influence student attitudes toward these and other subjects of a more practical nature.

There is the danger also that the prestige of the new projects together with the current emphasis in science might lead students to feel that certain subjects are of much less significance than the mathematics and sciences. The humanities are especially in danger of being undervalued by the students. In an age of increasing specialization, there is a need for education to broaden viewpoints. Snow's Two Cultures and the Scientific Revolution well illustrates the danger of overspecialization.

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[1] C. P. Snow, Two Cultures and the Scientific Revolution. Cambridge: Cambridge University Press, 1959.

By retaining balance in the curriculum the schools can make a significant contribution to the solution of the problem of specialization.

The suitability of the new projects for all students is another area of concern of the curriculum experts. The evidence on student achievement in the new projects presented in Chapter IV of this study revealed that low-ability students were not achieving at a rate commensurate with their ability. The material, at present, is too difficult for these students. What adjustments will be made in light of this fact are presently unknown. Both the chemistry and physics projects have been prepared for the same group of students who have studied these subjects in the past, the college bound. Since one of the avowed purposes of the new projects is to develop a citizenry capable of rendering intelligent decisions about science, the preparation of courses which will be limited to only a fraction of the future citizens appears incompatible with this purpose.

That teachers need special preparation to teach the new projects is recognized by the professional educators. The danger in regard to teacher preparation is that some schools, desiring to include the new projects in their curriculum, might assign inadequately prepared teachers to these projects. This danger has been recognized by several of the projects themselves. The Physical Science Study Committee, for example, will not approve a teacher for its course until he has completed a period of special instruction on teaching PSSC physics.

Some curriculum experts have questioned the curtailment or elimination of application and practical aspects of the subject matter in the new projects. The same concern has been expressed by the physicists in relation to the abstract nature of mathematics as presented in the mathematics projects. The physicists feel that the mathematicians have neglected to teach the students how, for instance, mathematics is used in science.

Since all students normally take mathematics and only a very small percentage of them will become mathematicians, the curriculum experts question the reduction of the application of mathematics to practical affairs. Students need to know how mathematics fits into their everyday life. Every citizen needs some knowledge of percentage and interest. Yet these topics have been greatly curtailed in the new mathematics projects.

The question of abstraction raises the issue of what is to be done for those students who are unable to master the work presented, a point raised earlier in the discussion on the suitability of the new projects for all students. Those persons planning the new projects have been silent on this point.

The professional educators have expressed concern about the subservience of individual talents and interests to national needs. The new programs in science have developed in large degree as a means of meeting the national need for more mathematicians and scientists. This demand has led to a program which is designed to cultivate those students who have scientific ability and lead them into the scientific field of work. The money made available to science and mathematics is indicative of the efforts being made. This emphasis on science and mathematics gives them a status which is higher than that of the other subjects. Our nation is willing to spend large sums of money to develop mathematicians and scientists but does little to encourage students into the humanities. The national program is geared to the needs of our society. The identification and development of individual talents and interests other than those in science and mathematics have been overlooked.

Chapter II of this study supports the assertion that there is little agreement about what a discipline is. The Woods Hole Conference failed to define the term. There was evidence, however, that the conference felt that any area of subject matter pursued by university scholars and scientists would be a discipline, provided that it was of an intellectual nature. In any event elementary and secondary school subjects derived from a field of scholarly or scientific study should be based on the structure developed by the scholars or scientists. To implement the disciplinary structure curriculum design described at the Woods Hole Conference requires that the subject-matter specialists agree on the structure of their field of study. This they have achieved in mathematics, physics, chemistry, and biology. It is of little importance whether or not these are considered to be disciplines by everyone. If the subject-matter specialists can agree on a structure to be taught this is all that is necessary.

Of course the scholars have not yet been able to agree about the structure of subjects such as English, history, economics, and the like.

The disciplines seminar sponsored by the National Education Association attempted to outline the structure of these and other subjects. However, no widespread agreements were reached.

As to which subject-matter areas should be taught, this is a decision to be made by the school boards. So far the new projects have reorganized subjects traditionally a part of the school curriculum. The author knows of no new subjects that have been developed by the advocates of teaching subject-matter structure. The problem of what subjects or disciplines should be taught is definitely not unique to the disciplinary structure curriculum design. This problem is shared by all curriculum patterns or designs.

The next reaction, that the methods of structuring mathematics and science might not be appropriate to other subjects, is closely related to the above discussion. Bruner, the chairman of the Woods Hole Conference, recognized this when he spoke of the structure of science and mathematics as being of the order of a generic condensation while that of literature and art has a metaphoric nature. The difference in the nature of the structure of these two groups of subjects may well explain why there is little agreement about the structure of the humanities and arts. It may be that only those subjects having structures based on generic condensations can follow the curriculum design proposed by the Woods Hole Conference. Research is needed in this area.

Curriculum experts have expressed the belief that teaching the structure of a discipline represents knowledge as abstract and fixed and results in the lack of an understanding of the method of inquiry of a discipline. There can be no doubt that emphasizing structure represents knowledge as abstract. This, however, according to the proponents of the disciplinary structure curriculum design, is desirable, for knowledge of the abstractions leads to the most effective transfer of learning, general rather than specific transfer. Specific transfer, which results from the knowledge of technology and application, is limited to transfer to situations very similar to those experiences during learning. General transfer, based on knowledge of abstraction, is much more widely applicable to new and relatively different situations from those comprising the learning experiences. Abstractness, then, is desired.

As to presenting knowledge as static, the disciplinary structure curriculum design is based upon the assumption that knowledge has a dynamic nature. Chapter II of this study discusses the changing nature of knowledge. This criticism of disciplinary structure curriculum design is unfounded.

One major aspect of teaching the structure of a discipline is to give the learner first-hand knowledge of its method of inquiry. Learning by discovery is proposed as one means of doing this. As was stated in Chapter VI one of the uses of discovery techniques is to give the learner an idea of how knowledge was developed in a discipline or subject. The scientific projects have developed their structure so that students can discover certain of the aspects for themselves. This is done so that the students will learn the method of inquiry used and the nature of the knowledge produced.

The comments presented above also pertain to the next reaction of the educators, that the structure of a discipline changes. Certainly if anyone should be aware that structure changes it should be the specialists in the area. One of the purposes of basing curriculum design on disciplinary structure was to keep the subject matter being presented in school up to date. By having the scholars and scientists continuously review the structure being taught, they can introduce the changes in structure when necessary.

The next reaction of the curriculum experts is to the effect that an extended period of time is required to teach the structure of a discipline effectively. It is the writer's opinion that the subject-matter specialists would agree with this. In fact, the School Mathematics Study Group has designed its program with this time factor in mind. Their work now extends from grade four through twelve. In presenting various aspects of mathematical structure they have used the principle of the spiral curriculum in planning sequence over a period of several years. Chapter III of this study presents a discussion of how this sequence is organized.

The reasons why the other projects have not followed suit are complex, but probably the main reason is that the projects had to work within the limits set by the common curriculum pattern. In other words the curriculum pattern did not seem to permit the scientists to follow the example of the mathematicians. However, the Woods Hole Conference did briefly recognize the possibility of such a plan. In speaking of specific scientific ideas the following question was raised. "Can these and similar ideas be presented effectively and with a variety of concrete illustrations in the early grades in order to give the child a better basis for understanding their specific representation in various special disciplines later?"[1] Further consideration was not given to this topic because the structure common to the various disciplines had not been identified. This section ended with the recognition that research was needed to determine if a common scientific structure could be developed.

Another reaction of the curriculum experts is that all students do not require the same degree of knowledge of disciplinary structure. The student who wishes to specialize in a subject-matter area in college would require more knowledge of structure than a student who does not expect to go to college. The subject-matter specialists feel that both types of students will acquire a better specialized and general understanding of a discipline if they approach the subject matter by means of its structure. They question that any will achieve a better knowledge of a subject by learning about it rather than learning it. The curriculum experts and the subject-matter specialists disagree on this point. There is no research known to the writer which supports either the specialists or the curriculum experts. Perhaps both groups might be well advised to plan research on this issue.

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[1] Bruner, The Process of Education, pp. 26-27.

The curriculum experts have expressed a fear that emphasizing disciplinary structure may lead to emphasizing those subjects most easily structured. The point being made here is that science, an easily structured subject, is concerned with the production of knowledge, not its use. Science does not tell us how to use the knowledge it produces. Value judgments, social norms, and the like direct the ways this knowledge is to be used. If emphasizing disciplinary structure leads to emphasizing those subjects most easily structured, then the importance of those subjects concerned with value judgments, ethics, and the like might suffer. Man must learn how to use his knowledge once he has produced it. The point being made is an important one. It was stated in the section of this chapter dealing with the implications of disciplinary structure curriculum design that this approach to curriculum design could not serve as the basis for the total school curriculum. The point raised by the curriculum experts provides additional evidence that other bases for curriculum design would be necessary to promote the ethical and moral values of society.

The last two reactions of the curriculum experts also indicate the limits of basing curriculum design upon the disciplinary structure design advocated by the Woods Hole Conference.

The first reaction calls attention to the fact that the structural approach to curriculum design does not provide a unified plan for curriculum organization. The educational goals sought by the advocates of the disciplinary structure design are largely limited to the intellectual aspects of education. The other goals of education require another basis of curriculum organization, for they require a different basis for structuring than that of mathematics and science. The nature of the structure of these subjects may not be compatible with the design of the disciplinary structure design as it is advocated by the Woods Hole Conference. The crux of this incompatibility may lie in the fact that mathematics and science have a logical structure while other subjects do not. Research is needed on this possibility.

The second reaction notes that no plan has been developed to relate the disciplines to each other or to the total school curriculum. The analysis and description presented in Chapter III indicated that the disciplinary structure approach to curriculum design follows the separate subjects pattern. It was also noted in Chapter III that there was little attempt to relate the work in one discipline to other disciplines. However, the disciplinary structure currriculum design approach does provide at least one basis for relating the subjects to each other, the similarity of structure that exists among the disciplines. Those subjects having similar structures could be correlated on this basis. The mathematicians have already done considerable work along these lines. Facets of algebra, geometry, and modern mathematics are being taught in the elementary schools as part of the arithmetic program. The extent to which this may be done in the other disciplines is at present unknown.

A review of the research failed to show, however, that any efforts were being made to relate the projects based on disciplinary structure to other subjects in the curriculum not organized by structure. At present, then, the disciplinary structure curriculum design is limited to mathematics and science. No plans for a unified curriculum have yet been devised. The criticism of the curriculum experts is a valid one.

A Further Critique

In addition to the critique made above, the writer wishes to offer several other points for consideration in criticizing the disciplinary structure curriculum design approach.

First, the report of the Woods Hole Conference raises about as many questions as it answers. The reporter for the conference was well aware of this and continually states that additional research is needed before many of the ideas and opinions expressed can effectively be evaluated.[1] It is apparent that much of the present work on disciplinary structure design has been carried on before adequate research was available. Of course, much of the work performed was done for purposes of research. Yet it is an interesting fact that so little research on the basic assumptions and ideas presented in The Process of Education has been undertaken.

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[1] For examples of the extent and degree of research recognized by the reporter, see Bruner, The Process of Education, pages 9, 13, 20, 21, 23, 25, 27, 28, and 29. These recognitions of the need for additional research are all contained in just the first two chapters.

Perhaps the most striking example of the lack of research is in relation to the four general advantages claimed for teaching the structure of a subject: (1) it makes a subject more comprehensible, (2) it improves memory, (3) it promotes transfer of training, and (4) it reduces the gap between elementary and advanced knowledge. In writing of these advantages Bruner states that "inherent in the preceding discussions are at least four general claims that can be made for teaching the fundamental structure of a subject, claims in need of detailed study."[1] In the review of the literature on disciplinary structure not a single study of the effects of teaching structure on any of the four claims was found. Apparently these claims have been assumed to be true. The same circumstances characterize most of the other ideas expressed in the report.

The research reported in Chapters IV and VI of this study is anything but conclusive. In general the results are ambiguous, so it cannot be determined how effective the new programs are. The most conclusive statement that can be made from the research is that those persons affiliated with the disciplinary structure projects believe them to be superior to the traditional courses.

The research comparing the achievement of students in both the traditional courses and the new projects shows that in general students studying the traditional courses do better on traditionally oriented achievement tests than do the students enrolled in the new projects. Likewise students studying the new projects do better on tests designed for the new projects than do students enrolled in the traditional course. This is hardly a surprising discovery. The advocates of the new projects state that they should be evaluated in terms of their own objectives, not in terms of the objectives of the traditional courses. This is true; however, only if the objectives sought by the new projects are judged to be those desired by the school. This last comment provides insight into the basic question to be considered when attempting to evaluate the new projects and the traditional courses. The main task is to determine which approach better promotes the objectives desired by the school. Once the objectives are understood a basis for selection is possible. For this reason any school system would be well advised to study carefully the objectives of the new projects.

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[1] The Process of Education, p. 23.

In addition to the objectives of the projects the school should be aware of the implications and critique listed earlier in this chapter and base its decision in part upon the degree to which the information provided indicates that the disciplinary structure curriculum design is compatible with the educational philosophy and general objectives of the school.

APPENDIX A

MEMBERS OF THE WOODS HOLE CONFERENCE WHO PARTICIPATED IN THE PSSC, SMSG, AND BSCS

Participant	Project
Dr. Edward Begle	SMSG
Dr. Henry Chauncey	PSSC
Mr. Gilbert Finlay	PSSC
Dr. Francis L. Friedman	PSSC, SMSG
Dr. Ralph Gerard	BSCS
Dr. H. Bentley Glass	BSCS
Dr. Arnold Grobman	BSCS
Dr. David L. Page	PSSC
Mr. Richard Pieters	SMSG
Dr. Paul C. Rosenbloom	SMSG
Dr. Herbert E. Vaughan	SMSG
Dr. Randall M. Whaley	PSSC
Dr. Jerrold Zacharias	PSSC

APPENDIX B

LIST OF CONTENTS OF SMSG TEXTBOOKS,

GRADES FOUR THROUGH TWELVE

Chapter	Title
	Grade 4
1	Concept of Sets
2	Numeration
3	Properties and Techniques of Addition and Subtraction, I
4	Properties of Multiplication and Division
5	Sets of Points
6	Properties and Techniques of Addition and Subtraction, II
7	Techniques of Multiplication and Division
8	Recognition of Common Geometric Figures
9	Linear Measurement
10	Concept of Fractional Number
	Grade 5
1	Extending Systems of Numeration
2	Factors and Primes
3	Extending Multiplication and Division
4	Congruence of Geometric Figures
5	Addition and Subtraction of Fractional Numbers
6	Measurement of Angles
7	Area
8	Ratio
9	Review Exercises
	Grade 6
1	Exponents
2	Multiplication of Fractional Numbers
3	Side-Angle Relationships of Triangles
4	The Integers

APPENDIX B--Continued

Chapter	Title
5	Coordinates
6	Division of Fractional Numbers
7	Volume
8	Organizing and Describing Data
9	Working with Numbers and Numerals Review
10	Sets and Circles
	Grade 7
1	What Is Mathematics?
2	Numeration
3	Whole Numbers
4	Nonmetric Geometry
5	Factoring and Primes
6	The Rational Number System
7	Measurement
8	Area, Volume, Weight, and Time
9	Ratios, Per Cents, and Decimals
10	Parallels, Parallelograms, Triangles, and Right Prisms
11	Circles
12	Mathematical Systems
13	Statistics and Graphs
14	Mathematics at Work in Science
	Grade 8
1	Rational Numbers and Coordinates
2	Equations
3	Scientific Notation, Decimals, and the Metric System
4	Constructions, Congruent Triangles, and the Pythagorean Property
5	Relative Error
6	Real Numbers
7	Permutations and Selections
8	Probability
9	Similar Triangles and Variation
10	Nonmetric Geometry
11	Volumes and Surface Areas
12	The Sphere
13	What Nobody Knows about Mathematics

APPENDIX B--Continued

Chapter	Title
	Grade 9
1	Sets and the Number Line
2	Numerals and Variables
3	Sentences and Properties of Operations
4	Open Sentences and English Sentences
5	The Real Numbers
6	Properties of Addition
7	Properties of Multiplication
8	Properties of Order
9	Subtraction and Division for Real Numbers
10	Factors and Exponents
11	Radicals
12	Polynomial and Rational Expressions
13	Truth Sets of Open Sentences
14	Graphs of Open Sentences in Two Variables
15	Systems of Equations and Inequalities
16	Quadratic Polynomials
17	Functions
	Grade 10
1	Common Sense and Organized Knowledge
2	Sets, Real Numbers and Lines
3	Lines, Planes, and Separation
4	Angles and Triangles
5	Congruences
6	A Closer Look at Proof
7	Geometric Inequalities
8	Perpendicular Lines and Planes in Space
9	Parallel Lines in a Plane
10	Parallels in Space
11	Areas of Polygonal Regions
12	Similarity
13	Circles and Spheres
14	Characterization of Sets; Constructions
15	Areas of Circles and Sectors
16	Volumes of Solids
17	Plane Coordinate Geometry

APPENDIX B--Continued

Chapter	Title
	Grade 11
1	Number Systems
2	An Introduction to Coordinate Geometry in the Plane
3	The Function Concept and the Linear Function
4	Quadratic Functions and Equations
5	Complex Number Systems
6	Equations of the First and Second Degree in Two Variables
7	Systems of Equations in Two Variables
8	Systems of First Degree Equations in Three Variables
9	Logarithms and Exponents
10	Introduction to Trigonometry
11	The System of Vectors
12	Polar Forms of Complex Numbers
13	Sequences and Series
14	Permutations, Combinations, and the Binomial Theorem
15	Algebraic Structures
	Grade 12
	First Semester
1	Functions
2	Polynomial Functions
3	Tangents to Graphs of Polynomial Functions
4	Exponential and Logarithmic Functions
5	Circular Functions
	Second Semester
1	Matrix Operations
2	The Algebra of 2 x 2 Matrices
3	Matrices and Linear Systems
4	Representation of Column Matrices as Geometric Vectors
5	Transformations of the Plane

APPENDIX C

SOURCES ON LEARNING BY DISCOVERY

The quotation or comment following each source provides evidence that the source meets the criteria of this study for learning by discovery. Additional evidence, of course, can be found by consulting the sources themselves.

Ashton, Sister Madeleine Rose. Heuristic Methods in Problem Solving in Ninth Grade Algebra. Doctor's thesis. Stanford: Stanford University, 1962. 125 pp. Abstract: Dissertation Abstracts 22:4289; No. 12, 1962.

> Here the pupils are made self-directive by learning to ask key questions such as: What is the unknown? What are the data? What are the conditions?
>
> In particular, students benefit by being allowed to find their own solutions, if they are helped sufficiently to give them direction and to keep them working. . . (p. 4289).

Ausubel, David P. "In Defense of Verbal Learning." Educational Theory 11:15-25; January 1961.

> At no stage does the learner have to discover principles independently in order to be able to understand and use them meaningfully (p. 24).

________. "Learning by Discovery: Rationale and Mystique." National Association of Secondary-School Principals Bulletin 45:18-58; December 1961.

> The most general and metaphysical of the nine propositions is the familiar assertion that to possess knowledge really or acquire an idea, the learner must discover it by himself or through his own insight (p. 25).

Bruner, Jerome S. "The Act of Discovery." Harvard Educational Review 31:21-32; Winter 1961.

> . . . discovery . . . is in its essence a matter of rearranging or transforming evidence in such a way that one is enabled to go beyond the evidence so reassembled to additional new insight (p. 22).

———. "After John Dewey, What?" Saturday Review 44:58-59, 76-78; June 17, 1961.

> In the first place, the child will make what he learns his own, will fit his discovery into the interior world of culture that he creates for himself (p. 77).

———. On Knowing. Cambridge, Mass.: Belknap Press of Harvard University Press, 1962. 165 pp.

This collection of essays contains "The Act of Discovery," "On Learning Mathematics," and "After John Dewey, What?" Therefore, there is no need to repeat the evidence from the other articles.

———. "On Learning Mathematics." Mathematics Teacher 53:610-19 December 1960.

> . . . any average teacher of mathematics can do much to aid his or her pupils to the discovery of mathematical ideas for themselves (p. 611).

———. The Process of Education. Cambridge, Mass.: Harvard University Press, 1960. 97 pp.

For evidence that learning by discovery is used in this report see pages 20-22.

Bruner, Jerome S.; Goodnow, Jacqueline J.; and Austin, George A. A Study of Thinking. New York: John Wiley and Sons, 1956. 330 pp.

> In the preceding chapters, we have been concerned with . . . the strategies by which people come to discover whatever they can

appropriately use for inferring the category membership of objects and events they may encounter (p. 231).

Butts, David P. The Degree to Which Children Conceptualize from Science Experiences. Doctor's thesis. Urbana: University of Illinois, 1962. 107 pp. Abstract: Dissertation Abstracts 23: 2418; No. 7, 1963.

These experiences were so structured that only that information which the student could secure from his own questions and manipulations would be available (p. 2418).

Carpenter, Finley. "The Effect of Different Learning Methods on Concept Formation." Science Education 40:282-85; October 1956.

[The functional group of] students go about the task of attempting to identify common characteristics of class members to discover the underlying principles that differentiate classes. They observe, manipulate materials, and test hunches in order to formulate an understanding of concepts rather than committing to memory each specific instance (p. 282).

Charen, George. "A Study of the Effect of Open-Ended Experiments in Chemistry on the Achievement of Certain Recognized Objectives of Science Education." Paper presented at the Thirty-Sixth Annual Meeting of the National Association for Research in Science Teaching, Washington, D. C., February 20-23, 1963. 16 pp. Based on the author's Doctor's thesis of the same title. Boulder: University of Colorado, 1962.

Open-ended experiments (MCA) are experiments which require students to seek solutions to problems using a method designed to be similar to that of genuine scientific inquiry. The outcomes cannot be anticipated before the start of the experiments (p. 3).

Craig, Robert C. "Directed versus Independent Discovery of Established Relations." Journal of Educational Psychology 47:223-34; April 1956.

The learning materials for the group who searched for principles with relatively little direction consisted of items organized on the same basis . . . grouped together and separated from other items by spacing (p. 226).

________. *The Transfer Value of Guided Learning.* New York: Bureau of Publications, Teachers College, Columbia University, 1953. 72 pp.

For evidence that learning by discovery is used in this study see pages 1-3 and 19-20.

Grote, Charles N. *A Comparison of the Relative Effectiveness of Direct-Detailed and Directed Discovery Methods of Teaching Selected Principles of Mechanics in the Area of Physics.* Doctor's thesis. Urbana: University of Illinois, 1960. 355 pp. Abstract: *Dissertation Abstracts* 21:3016-17; No. 10, 1961.

> The directed discovery method . . . placed a major responsibility upon the subject as an active participant in the study of meaningful materials . . . (p. 3016).

Haselrud, G. M., and Meyers, Shirley. "The Transfer Value of Given and Individually Derived Principles." *Journal of Educational Psychology* 49:293-98; December 1958.

> The hypothesis tested is that principles derived by the learner solely from concrete instances will be more readily used in a new situation than those given to him in the form of a statement of principle and an instance (p. 294).

Hendrickson, Gordon, and Schroeder, William H. "Transfer of Training in Learning to Hit a Submerged Target." *Journal of Educational Psychology* 32:205-13; March 1941.

> In the present study the importance of individual discovery of the solution--of the emergence of a sudden insight, in Gestalt terms--is apparent. In each group and for each problem the typical boy worked unsuccessfully for a time, then quite abruptly reached a solution (p. 213).

Hendrix, Gertrude. "Learning by Discovery." *Mathematics Teacher* 54: 290-99; May 1961.

> How do we know that both are *discovery*? Because a person can do them all by himself. The thing *learned* is not received by communication (p. 299).

________. "A New Clue to Transfer of Training." *Elementary School Journal* 48:197-208; December 1947.

Method II is the discovery group. See page 199-200 for evidence of this.

Huxtable, Zelma L. "Learning Outcomes Following Self-Directed and Formally Guided Responses in Controlled Situations." *Journal of Experimental Education* 6:406-12; June 1938.

> Specifically, the problem is to compare learning outcomes of eighth and ninth grade pupils whose responses are self-directed in given situations with the learning outcomes of the same pupils when their responses are formally guided in analogous situations (p. 406).

Kersh, Bert Y. "The Adequacy of 'Meaning' as an Explanation for the Superiority of Learning by Independent Discovery." *Journal of Educational Psychology* 49:282-92; October 1958.

> One group of S_s [subjects], called the "no-help" group, was required to discover the rules without help (p. 283).

________. "Learning by Discovery: A Review of Recent Literature." Paper presented at the Symposium of the American Educational Research Association, Atlantic City, New Jersey, February 20, 1962. 6 pp.

For evidence that the criteria are satisfied by the research studies reviewed by Kersh, check these studies against this appendix.

________. "The Motivating Effect of Learning by Directed Discovery." *Journal of Educational Psychology* 53:65-71; April 1962.

> A second group, called the Guided Discovery group, was required to discover the explanation with guidance from the experimenter. The subjects in the Guided Discovery group were taught tutorially using a form of Socratic questioning which required each subject to perform specific algebraic manipulations and to make inferences without help (p. 67).

Kittell, Jack E. "An Experimental Study of the Effect of External Direction during Learning on Transfer and Retention of Principles." *Journal of Educational Psychology* 48:391-405; November 1957.

The purpose of this experiment was to determine the relative effects of three amounts of direction to learners in their discovery of established principles on transfer to different situations and on retention of learned principles (p. 403).

Moss, Jerome, Jr. *An Experimental Study of the Relative Effectiveness of the Direct-Detailed and the Directed Discovery Methods of Teaching Letterpress Imposition.* Doctor's thesis. Urbana: University of Illinois, 1960. 293 pp. Abstract: *Dissertation Abstracts* 21: 2992; No. 10, 1961.

[This group used] . . . the directed discovery method, providing direct, positive instruction for only that content considered basic, and relying upon carefully structured and ordered questions and hints to facilitate subjects' discovery of the remaining information and functional relationships to be acquired and understood (p. 2992).

Ray, Willis E. "Pupil Discovery versus Direct Instruction." *Journal of Experimental Education* 29:271-80; March 1961.

LL

Method B . . . could be characterized as a method of "directed discovery." By this method the pupil was called upon to be active, to carefully study illustrative material on his own, and contemplate leading questions asked by the teacher. . . . Very few positive statements of fact and none of principle or generalization were given orally by this method (p. 272).

Rowlett, John D. *An Experimental Comparison of Direct-Detailed and Directed Discovery Methods of Teaching Orthographic Projection Principles and Skills.* Doctor's thesis. Urbana: University of Illinois, 1960. 239 pp. Abstract: *Dissertation Abstracts* 20: 4589-90; No. 12, 1960. LC

The directed discovery method, a method involving leading questions and "hints" was contrasted with a direct-detailed procedure involving highly specific instructions (p. 4589).

Schwab, Joseph J., and Brandwein, Paul F. The Teaching of Science. 1961 Inglis Lecture in Secondary Education and the 1961 Burton Lecture in Elementary Education. Cambridge, Mass.: Harvard University Press, 1962. 152 pp.

For evidence that learning by discovery is used in this study, see pages 52-60.

Sechrest, Lee, and Wallace, John. "Assimilation and Utilization of Information in Concept Attainment under Varying Conditions of Information Presentation." Journal of Educational Psychology 53: 157-64; August 1962.

[The following directions were given to all subjects.] This is an experiment in what is called concept attainment. Throughout this session you will be asked to try to discover concepts . . . which I have in mind (p. 158-59).

Shore, Eugene, and Sechrest, Lee. "Concept Attainment as a Function of Number of Positive Instances Presented." Journal of Educational Psychology 52:303-307; December 1961.

Two experiments were carried out in an attempt to determine whether concepts are more easily discovered from the repeated examinations of a few instances of the concept or from single examinations of large numbers of instances (p. 306).

Stacey, Chalmers L. "The Law of Effect in the Retained Situation with Meaningful Material." In Learning Theory in School Situations. University of Minnesota, Studies in Education, College of Education, No. 2. Minneapolis: University of Minnesota Press, 1949. pp. 74-103.

In the present experiment subjects participated in two divergent learning procedures. One was a process that required self-discovery on the part of the learner. . . (p. 101).

Suchman, J. Richard. The Elementary School Training Program in Scientific Inquiry. Title VII Project Number 216, National Defense Education Act of 1958. Grant No. 7-11-038. Urbana: University of Illinois, 1962. 188 pp.

We put children in a position where they can learn only through self-initiated and self-implemented quests for information. A

problem is posed in the form of a motion picture of a short physics demonstration. The children are confronted with the question "Why?" They must search for what they need in order to piece together an explanation (p. 21).

________. "Inquiry Training: An Approach to Problem Solving." Laboratories in the Classroom. New York: Science Materials Center, 1960. pp. 73-76.

This is a further explanation of the Elementary School Training Program in Scientific Inquiry.

________. "Inquiry Training: Building Skills for Autonomous Discovery." Merrill-Palmer Quarterly 7:147-69; July 1961.

The article also provides a description of the Elementary School Training Program in Scientific Inquiry.

________. "Inquiry Training in the Elementary School." Science Teacher 27:42-47; November, 1960.

This is another description of the Elementary School Training Program in Scientific Inquiry.

________. "Making Room for Searching Minds: Prospects for Education through Inquiry." Paper presented at the Leadership Conference sponsored by the California State Department of Education at Asilomar, California, August 8-12, 1962. 12 pp.

The Elementary School Training Program in Scientific Inquiry is also described in this paper.

Taba, Hilda. "Learning by Discovery: Psychological and Educational Rationale." Elementary School Journal 63:308-16; March 1963.

The learner must construct his own conceptual schemata with which to process and to organize whatever information he receives (p. 311).

APPENDIX D

SOURCES OF VARIOUS TYPES OF LEARNING BY DISCOVERY

Autonomous Discovery

Suchman, J. Richard. "Inquiry Training: Building Skills for Autonomous Discovery." Merrill-Palmer Quarterly 7:147-69; July 1961.

Concept Attainment

Bruner, Jerome S., Goodnow, Jacqueline J., and Austin, George A. A Study of Thinking. New York: John Wiley and Sons, 1956. 330 pp.

Sechrest, Lee, and Wallace, John. "Assimilation and Utilization of Information in Concept Attainment under Varying Conditions of Information Presentation." Journal of Educational Psychology 53:157-64; August 1962.

Shore, Eugene, and Sechrest, Lee. "Concept Attainment as a Function of Number of Positive Instances Presented." Journal of Educational Psychology 52:303-307; December 1961.

Directed Discovery

Craig, Robert C. "Directed versus Independent Discovery of Established Relations." Journal of Educational Psychology 47:223-34; April 1956.

Grote, Charles N. A Comparison of the Relative Effectiveness of Direct-Detailed and Directed Discovery Methods of Teaching Selected Principles of Mechanics in the Area of Physics. Doctor's thesis. Urbana: University of Illinois, 1960. 355 pp. Abstract: Dissertation Abstracts 21:3016-17; No. 10, 1961.

Kersh, Bert Y. "The Motivating Effect of Learning by Directed Discovery." Journal of Educational Psychology 53:65-71; April 1962.

Moss, Jerome, Jr. An Experimental Study of the Relative Effectiveness of the Direct-Detailed and the Directed Discovery Methods of Teaching Letterpress Imposition. Doctor's thesis. Urbana: University of Illinois, 1960. 293 pp. Abstract: Dissertation Abstracts 21: 2992; No. 10, 1961.

Rowlett, John D. An Experimental Comparison of Direct-Detailed and Direct Discovery Methods of Teaching Orthographic Projection Principles and Skills. Doctor's thesis. Urbana: University of Illinois, 1960. 239 pp. Abstract: Dissertation Abstracts 20: 4589-90; No. 12, 1960.

Guided Discovery

Craig, Robert C. The Transfer Value of Guided Learning. New York: Bureau of Publications, Teachers College, Columbia University, 1953. 72 pp.

Independent Discovery

Craig, Robert C. "Directed versus Independent Discovery of Established Relations." Journal of Educational Psychology 47:223-34; April 1956.

Kersh, Bert Y. "The Adequacy of 'Meaning' as an Explanation for the Superiority of Learning by Independent Discovery." Journal of Educational Psychology 49:282-92; October 1958.

Individually Derived Principles

Haselrud, G. M., and Meyers, Shirley. "The Transfer Value of Given and Individually Derived Principles." Journal of Educational Psychology 49:293-98; December 1958.

Inquiry

Suchman, J. Richard. The Elementary School Training Program in Scientific Inquiry. Title VII Project Number 216, National Defense Education Act of 1958. Grant No. 7-11-0380. Urbana: University of Illinois, 1962. 188 pp.

________. "Inquiry Training: An Approach to Problem Solving." Laboratories in the Classroom. New York: Science Materials Center, 1960. pp. 73-76.

________. "Inquiry Training: Building Skills for Autonomous Discovery." *Merrill-Palmer Quarterly* 7:147-69; July 1961.

________. "Inquiry Training in the Elementary School." *Science Teacher* 27:42-47; November 1960.

________. "Making Room for Searching Minds: Prospects for Education through Inquiry." Paper presented at the Leadership Conference sponsored by the California State Department of Education at Asilomar, California, August 8-12, 1962. 12 pp.

Open-Ended Experiments

Charen, George. "A Study of the Effect of Open-Ended Experiments in Chemistry on the Achievement of Certain Recognized Objectives of Science Education." Paper presented at the Thirty-Sixth Annual Meeting of the National Association for Research in Science Teaching, Washington, D. C., February 20-23, 1963. 16 pp.

Self-Discovery

Huxtable, Zelma L. "Learning Outcomes Following Self-Directed and Formally Guided Responses in Controlled Situations." *Journal of Experimental Education* 6:406-12; June 1938.

Stacey, Chalmers L. "The Law of Effect in the Retained Situation with Meaningful Materials." In *Learning Theory in School Situations.* University of Minnesota, Studies in Education, College of Education, No. 2. Minneapolis: University of Minnesota Press, 1949. pp. 74-103.

APPENDIX E

SOURCES ADEQUATELY DEFINING TERMS

Bruner, Jerome S., Goodnow, Jacqueline J., and Austin, George A. *A Study of Thinking*. New York: John Wiley and Sons, 1956. 330 pp.

Craig, Robert C. "Directed versus Independent Discovery of Established Relations." *Journal of Educational Psychology* 47:223-34; April 1956.

________. *The Transfer Value of Guided Learning*. New York: Bureau of Publications, Teachers College, Columbia University, 1953. 72 pp.

Haselrud, G. M., and Meyers, Shirley. "The Transfer Value of Given and Individually Derived Principles." *Journal of Educational Psychology* 49:293-98; December 1958.

Hendrickson, Gordon, and Schroeder, William H. "Transfer of Training in Learning to Hit a Submerged Target." *Journal of Educational Psychology* 32:205-13; March 1941.

Kersh, Bert Y. "The Adequacy of 'Meaning' as an Explanation for the Superiority of Learning by Independent Discovery." *Journal of Educational Psychology* 49:282-92; October 1958.

Kittell, Jack E. "An Experimental Study of the Effect of External Direction during Learning on Transfer and Retention of Principles." *Journal of Educational Psychology* 48:391-405; November 1957.

Sechrest, Lee, and Wallace, John. "Assimilation and Utilization of Information in Concept Attainment under Varying Conditions of Information Presentation." *Journal of Educational Psychology* 53: 157-64; August 1962.

Stacey, Chalmers L. "The Law of Effect in the Retained Situation with Meaningful Materials." In *Learning Theory in School Situations*. University of Minnesota, Studies in Education, College of Education, No. 2. Minneapolis: University of Minnesota Press, 1949. pp. 74-103.

Suchman, J. Richard. The Elementary School Training Program in Scientific Inquiry. Title VII Project Number 216, National Defense Education Act of 1958. Grant No. 7-11-038. Urbana: University of Illinois, 1962. 188 pp.

APPENDIX F

SOURCES ON AUTONOMOUS DISCOVERY METHODS

If the source includes more than one type of learning by discovery, the autonomous discovery group is given after the source.

Bruner, Jerome S., Goodnow, Jacqueline J., and Austin, George A. A Study of Thinking. New York: John Wiley and Sons, 1956. pp. 96-103. Random Group.

Craig, Robert C. The Transfer Value of Guided Learning. New York: Bureau of Publications, Teachers College, Columbia University, 1953. pp. 25-26. Guidance Z, nonguidance.

Hendrickson, Gordon, and Schroeder, William H. "Transfer of Training in Learning to Hit a Submerged Target." Journal of Educational Psychology 32:205-13; March 1941. Control Group.

Sechrest, Lee, and Wallace, John. "Assimilation and Utilization of Information in Concept Attainment under Varying Conditions of Information Presentation. Journal of Educational Psychology 53: 157-64; August 1962. Condition I.

Suchman, J. Richard. The Elementary School Training Program in Scientific Inquiry. Title VII Project Number 216, National Defense Education Act of 1958. Grant No. 7-11-038. Urbana: University of Illinois, 1962.

APPENDIX G

SOURCES ON GUIDED DISCOVERY METHODS

If the source includes more than one type of learning by discovery, the guided discovery group is given after the source.

Bruner, Jerome S., Goodnow, Jacqueline J., and Austin, George A. A Study of Thinking. New York: John Wiley and Sons, 1956. pp. 96-103. Ordered Group.

Craig, Robert C. The Transfer Value of Guided Learning. New York: Bureau of Publications, Teachers College, Columbia University, 1953. pp. 26-27. Guidance G.

Kersh, Bert Y. "The Adequacy of 'Meaning' as an Explanation for the Superiority of Learning by Independent Discovery." Journal of Educational Psychology 49:282-92; October 1958. "No-help" Group.

Sechrest, Lee, and Wallace, John. "Assimilation and Utilization of Information in Concept Attainment under Varying Conditions of Information Presentation." Journal of Educational Psychology 53:157-64; August 1962. Conditions II and III.

APPENDIX H

SOURCES ON DIRECTED DISCOVERY METHODS

If the source included more than one type of learning by discovery, the directed discovery group is given after the source.

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Kittell, Jack E. "An Experimental Study of the Effect of External Directions during Learning on Transfer and Retention of Principles." Journal of Educational Psychology 48:391-405; November 1957. Minimum Direction Group.

APPENDIX I

TYPICAL SESSION OF INQUIRY TRAINING[a]

First the students see a film which shows that a brass ball is barely able to pass through a brass ring. The ball is heated and placed on the ring which is held in a horizontal position. The ball does not immediately pass through the ring; however, after the lapse of several minutes the ball drops through. The students are asked to seek an explanation for what they have seen. The questioning begins:

"Pupil: Were the ball and ring at room temperature to begin with?
Teacher: Yes.
Pupil: And the ball would go through the ring at first?
Teacher: Yes.
Pupil: After the ball was held over the fire it did not go through the ring, right?
Teacher: Yes.
Pupil: If the ring had been heated instead of the ball, would the results have been the same?
Teacher: No.
Pupil: If both had been heated would the ball have gone through then?
Teacher: That all depends.
Pupil: If they had both been heated to the same temperature would the ball have gone through?
Teacher: Yes.
Pupil: Would the ball be the same size after it was heated as it was before?
Teacher: No.
Pupil: Could the same experiment have been done if the ball and ring were made out of some other metal?
Teacher: Yes."

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[a] J. Richard Suchman, "Inquiry Training in the Elementary School." *Science Teacher* 27:42; November 1960.

APPENDIX J

SOURCES OF DISCOVERY METHODS USED TO TEACH ONLY SUBJECT MATTER CONTENT OR SKILLS

These sources use discovery methods to teach various kinds of subject matter content. After each source the type of content taught is given in parentheses.

Butts, David P. *The Degree to Which Children Conceptualize Science Experience.* Doctor's thesis. Urbana: University of Illinois, 1962. 107 pp. Abstract: *Dissertation Abstracts* 23:2418; No. 7 1963. (Physics.)

Grote, Charles N. *A Comparison of the Relative Effectiveness of Direct-Detailed and Directed Discovery Methods of Teaching Selected Principles of Mechanics in the Area of Physics.* Doctor's thesis. Urbana: University of Illinois, 1960. 355 pp. Abstract: *Dissertation Abstracts* 21:3016-17; No. 10. 1960. (Physics.)

Hendrickson, Gordon, and Schroeder, William H. "Transfer of Training in Learning to Hit a Submerged Target." *Journal of Educational Psychology* 32:205-13; March 1941. (Physics.)

Hendrix, Gertrude. "A New Clue to Transfer of Training." *Elementary School Journal* 48:197-208; December 1947. (Mathematics.)

Huxtable, Zelma T. "Learning Outcomes Following Self-Directed and Formally Guided Responses in Controlled Situations." *Journal of Experimental Education* 6:406-12; June 1938. (English.)

Kersh, Bert Y. "The Adequacy of 'Meaning' as an Explanation for the Superiority of Learning by Independent Discovery." *Journal of Educational Psychology* 49:282-92; October 1958. (Mathematics.)

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Byers, Joey L. *Strategies and Learning Set in Concept Attainment.* Doctor's thesis. Madison: University of Wisconsin, 1961. 101 pp. Abstract: *Dissertation Abstracts* 22:1904; No. 6, 1961.

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BIOGRAPHICAL SKETCH

William Woods Stokes was born in Panama City, Florida, on May 28, 1932. He attended public schools in Panama City, graduating from Bay County High School in June, 1950. The following September he entered the University of Florida. In June, 1954, he received the degree of Bachelor of Arts in Education and immediately entered the United States Army. Following his discharge from the Army, he began teaching at Kirby-Smith Junior High School, Jacksonville, Florida. In 1959 he enrolled in the Graduate School of the University of Florida. In February, 1960, he received the degree Master of Education. From February, 1960, until the present time he has pursued his work toward the degree of Doctor of Education.

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This dissertation was prepared under the direction of the chairman of the candidate's supervisory committee and has been approved by all members of that committee. It was submitted to the Dean of the College of Education and to the Graduate Council, and was approved as partial fulfillment of the requirements for the degree of Doctor of Education.

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